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EPA-440/5-78-004

MITIGATION FEASIBILITY for the KEPONE-CONTAMINATED HOPEWELL/JAMES RIVER AREAS

JUNE 9, 1978

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER AND HAZARDOUS MATERIALS
CRITERIA AND STANDARDS DIVISION
WASHINGTON, D.C. 20460

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The report documents the results of the U.S. EPA Kepone Mitigation Feasibility Project for the Hopewell James River Virginia area, describing: the chronological development of the Kepone contamination problem from 1966 to 1978, the nature of Kepone contamination in Hopewell, and the/James River; Kepone effects and impacts; evaluation of methods to mitigate the problem; and the resultant findings and recomendations. The Appendices to the report document the efforts of the individual funded participants.

The report findings provide a basis for limiting the impact of Kepone contamination. Field Sampling and modeling studies delineate areas requiring special attention. Analyses of a wide range of research studies on the biota affected by Kepone provide guidance on both continuing impacts and promising areas of investigation. Engineering, field, and laboratory analyses of world-wide conventional (dredging) and nonconventional mitigation methods (physical, biological and chemical) have established fruitful areas of development and eliminated others which are ineffective or hazardous. The analysis and synthesis of engineering and biological studies, modeling studies and field investigations provides a useful reference source to approach other serious in place toxic pollutant problems in this country's waterways.

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Hazardous substances	In-place toxicants	
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Dredging	Dredge spoil fixation	
Dredge spoil management	In-place fixation	
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MITIGATION FEASIBILITY
for the
KEPONE-CONTAMINATED
HOPEWELL/JAMES RIVER AREAS

BY

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JUNE 9, 1978

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER AND HAZARDOUS MATERIALS
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FOREWORD

In the Fall of 1976, the Governors of Virginia and Maryland jointly requested that EPA evaluate the Kepone problem in the Hopewell, Virginia area and James River system and explore corrective or mitigative actions.

In response to this request, EPA Headquarters initiated the Kepone Mitigation Feasibility Project. The project support teams included: the U.S. Army Corps of Engineers, Norfolk District; the Department of Energy, Battelle Pacific Northwest Laboratories; EPA's Gulf Breeze Environmental Research Laboratory; and the Virginia Institute of Marine Science. Coordination channels were also established with the States of Virginia and Maryland, and other related staffs and agencies. The intensive on-going cooperation, critique and review provided by the States of Virginia and Maryland were a major contribution to the effectiveness of the research and quality of the results.

The tight deadlines established for the project necessitated completion of many participant tasks simultaneously, which ideally would have been accomplished sequentially. A sequential programming of such tasks would have required two to three years, rather than the one year originally allotted. The great interdependence of many of the separate participant tasks required establishment of conditional findings and conclusions in their separate reports. Accordingly, the overall project findings and recommendations are reflected in this report.

There are no easy solutions to the Kepone contamination problem. The work accomplished under the project should provide the basis for focusing efforts on the most critical issues and promising solutions. In addition, the investigation of applicable technologies for mitigation will be useful in addressing other similar contamination problems.

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A. Department of Energy - Battelle Pacific Northwest Laboratories
B. Department of The Army - Corps of Engineers, Norfolk District
C. EPA Gulf Breeze Environmental Research Laboratory and Virginia Institute of Marine Science

KEPONE MITIGATION FEASIBILITY PROJECT

EXECUTIVE SUMMARY

INTRODUCTION

The hazard of highly persistant, toxic substances contaminating large land and water areas is a problem of continuing concern worldwide. The Kepone problem in Hopewell, Virginia surfaced through deleterious effects on production worker's health at the Kepone production plant of Life Science Products. Three years after the closedown of the production site, contamination still persists in the Hopewell area and in the James River.

In the Fall of 1976, the Governors of Virginia and Maryland jointly requested that EPA evaluate the Kepone problem in the James River system and explore corrective or mitigative actions. In response to this request, a plan was proposed in November 1976. Phase I involved an assessment of: suspected continuing sources of Kepone contamination; the fate and transport of Kepone in the James River system; the current and long-range effects of Kepone contamination on the biota; and an evaluation of mitigation and removal methods. An allocation of $1.4 million was made for support studies in Phase I. The project was initiated on March 31, 1977. Following review of recommendations by EPA and the States of Virginia and Maryland, Phase

II could involve a decision to: seek funding for a major cleanup or mitigation program; proceed with pilot testing of alternative corrective actions; or withhold action.

Project development and management responsibility was assigned to the Criteria and Standards Division of EPA with project participants including: the Corps of Engineers (COE); the Department of Energy (DOE); Battelle Pacific Northwest Laboratories; EPA's Gulf Breeze Environmental Research Laboratory; and the Virginia Institute of Marine Science. Extensive on-going coordination has been accomplished with the States of Virginia and Maryland, EPA's Region III, and other elements of EPA. Information also has been exchanged with the State of New York's PCB Task Force which faced a similar river contamination problem.

This report documents the results of the project effort, describing: the nature of the Kepone contamination in the Hopewell, Virginia/James River area; Kepone effects and impacts; efforts undertaken by the Kepone Mitigation Feasibility Project to assess the problem and determine solutions; and the resulting findings and recommendations. The Appendices to the report document the efforts of the individual funded participants.

BACKGROUND

Kepone, a highly chlorinated hydrocarbon pesticide, was discharged into the environment around Hopewell, Virginia from 1966 to 1975 from two manufacturing operations. The Allied Chemical Corporation's Semi-Works Plant produced Kepone intermittently from 1966 to 1974. Life Science Products Company initiated Kepone production under contract to Allied Chemical in 1974 and continued production until closure of the plant in Sept. 1975. Fish and sediment samples indicate Kepone contamination existed in the James River as early as 1967.

Early warnings of Life Science Products' careless manufacturing and disposal practices were apparent with the malfunctioning of the digestors of the Hopewell sewage treatment plant and the deleterious health effects on the production workers. Subsequently, the finding of high levels of Kepone contamination in James River fish brought about a ban on fishing for a wide range of species. The releases from the Life Science Products plant into the environment were associated with atmospheric emissions, wastewater discharges and bulk disposal of off-specification batches. The atmospheric emissions from the plant settled on the surface soils. Wastewater discharges entering the sewage system passed through the Hopewell sewage treatment plant into Bailey Creek, passing into Bailey Bay and the James River. Disposal of off-specification batches and manufacturing residues of Kepone occurred at a minimum of two sites - the Hopewell landfill and a disposal trench at the former Pebbled Ammonium Nitrate Plant. Following closure of Life Science Products, residues from the dismantled plant and site cleanup were buried at the landfill. Drummed residues from Kepone production were stored at the Hopewell sewage treatment plant and at Portsmouth, Virginia. Kepone-contaminated sludge from the Hopewell sewage treatment plant was stored in a lagoon constructed at the sewage treatment plant site.

Almost three years following the closure of the Life Science Products plant, the disposal of the drummed Kepone production residues and the Kepone-contaminated sludge is unresolved. Several sites in the City of Hopewell contain Kepone; small inflows of Kepone continue into the James River, and the levels of contamination remain sufficiently high to cause continued closure of the James River to recreational and commercial fishing for many species of fish and shellfish.

Litigation related to the Kepone incident has continued. The original indictments against Allied Chemical Corporation, the City of Hopewell and executives of the Life Science Products Company resulted in large fines - $13.2 million in the case of Allied Chemical Corporation. However, several workers suits remain unresolved. The State of Virginia recently settled part of its claims against Allied Chemical for $5.25 million, but reserves the right to sue Allied

Chemical for cleanup of the James River, and disposal of stored Kepone residuals.

Allied Chemical is being sued in a Class Action Suit (Pruitt vs. Allied Chemical Corp.) on behalf of all the people in the Chesapeake Bay region who have lost income because of the Kepone incident. In addition, there are two watermen suits (Adams and Ferguson). Their suits against Allied Chemical are for loss of fishing from the closed James River.

SCOPE OF PROJECT

The immensity of the Kepone contamination problem, the limited U.S. experience in handling in-place toxic pollutant problems of this type, and other constraints on the Kepone Mitigation Feasibility Project limited the effort to specific areas. The project's primary focus was to evaluate the extent of the contamination, its fate and transport, and explore mitigation alternatives. A full-scale environmental assessment, an economic analysis of the effects of the contamination and a cost/benefit analysis of potential cleanup options were beyond the scope of the project. Furthermore, the project represents only one of a series of past and continuing efforts to fully assess and seek solutions to the Kepone contamination problem. For example, the States of Virginia and Maryland both have substantial continuing programs to monitor and assess the Kepone problem. In addition, the State of Virginia has formulated a long-range plan to deal with the Kepone problem.

Despite constraints in time and scope, the project findings should provide a sound foundation for progress in mitigating the Kepone contamination problem and/or limiting the impact of the contamination. For example, more than 900 soil and sediment samples, combined with the continuing sampling programs of the States of Virginia and Maryland, have materially elucidated the extent of contamination and delineated areas requiring special attention. The analyses of a wide range of research studies on the biota affected by Kepone have provided guidance on both continuing impacts and promising areas of investigation. The engineering, field, and laboratory analyses of both conventional and nonconventional mitigation methods have established fruitful areas of development and eliminated others which are ineffective or hazardous.

Finally, the analysis and synthesis of engineering and biological studies, modeling studies and field investigations should provide a useful reference source to move forward with a sense of perspective on mitigation of the Kepone problem and to approach other serious waterway contamination problems in this country.

FINDINGS and RECOMMENDATIONS

The following findings and recommendations result from the investigations of the Kepone Mitigation Feasibility Project. The findings and recommendations are divided into four parts, those relative to: the James River, the Chesapeake Bay, the Hopewell area, and recommended research.

James River Findings

- Estimates indicate that there are 9,000 to 17,000 kg (20,000 to 38,000 lb) of Kepone in the top one foot of James River sediments. Estimates for deeper sediments cannot be made reliably because of a lack of investigative data. However, the top foot of sediment is believed to contain most of the Kepone.

- Most of the Kepone in the James River is associated with the sediments, with much lesser amounts found in the water.

- Based on current evidence, degradation of Kepone in the natural environment is insignificant.

- Laboratory experiments indicate that organisms bioconcentrate Kepone to concentrations near or above the FDA Action Levels for finfish and shellfish, where Kepone levels are near the limits of detectability (0.02 ug/l (ppb) for water and 0.02 ug/g (ppm) for sediment). Blue crabs were shown in laboratory experiments to concentrate Kepone in their tissues; they died, or molted less frequently than normally from eating Kepone-contaminated food at levels comparable to those found in James River organisms.

- Additional field data on the impact of Kepone on a wider range of James River fish and shellfish is needed.

- Present data indicate that it will take decades for natural dispersion mechanisms to cause concentrations of Kepone in the James River biota to decrease below current FDA Kepone Action Levels of 0.3 ug/g (ppm) for finfish and shellfish and 0.4 ug/g (ppm) in crabs.

- The National Cancer Institute (NCI) and the National Institute of Environmental Health (NIEH) have proposed and will begin shortly a joint study to re-examine the potential carcinogenicity of Kepone. The results of this study may impact on the current FDA Action Levels.

- Modeling and laboratory-derived coefficients, show that an average discharge of 89 kilograms (195.8 lb) per year of Kepone leave Burwell Bay downstream, of which 66.6 kg (146.5 lb) is dissolved in the water and 22.5 kg (49.5 lb) is attached to suspended sediments.

- Calculations indicate that an additional 72 kilograms (158.4 lb) of Kepone may leave the James River in the tissues of migratory fish.

- The present navigational dredging practice in the Kepone contaminated portion of the James River is to discharge the removed dredged material back into the river away from the navigational channel.

- Adequate dredge spoil facilities could be designed and developed along the James River, but further investigation is needed to identify and evaluate disposal sites.

- Based on modeling analysis, cleanup programs which address only the areas of concentrated Kepone contamination will not effectively reduce Kepone residuals in the short term in James River biota below the current FDA Action Levels.

- Mitigation efforts for Kepone contamination would involve disruption or removal of sediment from 200 square miles of river bottom.

- The projected cost for effectively eliminating Kepone contamination from the James River is in the billions of dollars.

- The ecological consequences of large-scale bottom sediment alterations are large but unquantified.

- Kepone concentration levels in Bailey Bay are sufficiently high to yield reliable test results on the effectiveness of new technology for Kepone mitigation.

- If dredging is considered, Bailey Bay, which contains approximately 595 kg (1,200 lb) of Kepone, could provide a diked disposal site with multiple benefits. Dredge spoil deposited on top of Bailey Bay sediments would cover and isolate the in-place high Kepone levels and would provide an effective disposal site for Kepone-contaminated sediments, removed during maintenance dredging.

- Operational technology exists in the area of spoil fixation and in situ stabilization. A proven operational spoil fixation and in situ stabilization technique for handling in-place toxic pollutants is available. This fixation system has been used effectively on sludge/sediments contaminated by mercury, copper, zinc, cadmium, lead, chromium and PCBs. Laboratory tests have shown the fixation process to be effective on arsenic as well. Current development results appear promising for Kepone.

- The Japanese Oozer dredge is capable of high solids removal and low secondary pollution via secondary suspension. If dredging is employed for mitigation, use of the Oozer will reduce elutriate treatment requirements and permit the use of smaller disposal areas.

- The UV-ozone treatment process has demonstrated an effective capability for the destruction of Kepone in slurries of high solids content. Preliminary cost estimates, not including equipment amortization, are extremely favorable at $0.10 to $0.20 per cubic yard for slurries containing 20 to 50 percent solids.

- A temporary filtration/adsorption wastewater treatment system appears to be practical for elutriate treatment. The effectiveness of activated carbon in treating Kepone was demonstrated with the clean-up of the Life Science Products plant site.

- Several techniques for adsorbing Kepone from sediments and fixing sediments show some promise in laboratory evaluations, but would require extensive additional laboratory investigation before their operational utility could be addressed.

James River Recommendations

- Based on the enormous costs of total James River amelioration efforts, the lack of knowledge on ecological impacts of widespread mitigation efforts, the unavailability of economic impact determinations, and supportive evidence that most of the Kepone will remain in the zone of turbidity maximum, no full-scale cleanup action on the James River should be undertaken at this time.

- The Oozer dredge should be seriously considered for any navigational dredging in the turbidity maximum. Navigational dredged spoil from Kepone-contaminated "hot-spots" should not be disposed overboard, but be placed in adequately protected dredge spoil sites developed along the James River.

- Further evaluation of potential mitigation technologies should be initiated to provide knowledge for immediate response to unpredicted movement of Kepone in the James River. Among the technologies to be given priority evaluation are fixation techniques, UV-ozone treatment and activated carbon processes for elutriate treatment.

- Based on the demonstrated operational capabilities of a fixation system on other contaminants and promising results with Kepone, developmental funding should be provided to continue specific Kepone fixation investigations.

- The promising UV-ozone treatment should be funded for performing bench tests to define approximate operating parameters, including costs, for various slurry concentrations, and to conduct concurrent chemical analyses to determine the degree of degradation of Kepone by UV-ozone required to negate Kepone's toxicity.

- In light of the proposed NCI and NIEH joint carcinogenicity study and with the implications to commercial fishing of long-term closure of the James River, the present FDA Action Levels of 0.3 ug/g (ppm) for finfish and shellfish and 0.4 ug/g (ppm) for crabs should be re-examined and re-evaluated.

- Systematic monitoring of Kepone levels in water, sediment and biota should be continued in the tidal James River by the State of Virginia, in order to provide warning of unexpected movements of Kepone contamination toward Chesapeake Bay.

Chesapeake Bay Findings

- Present evidence regarding the potential spread of Kepone contamination, including historical trends, recent sampling data, and transport projections, does not provide justification for Kepone cleanup actions in the James River to protect the Chesapeake Bay. The data indicate no imminent danger of Kepone contamination to the Chesapeake Bay at this time. However, major coastal storms and like events could alter these predictions.

- While early Kepone sediment tests of the James River are few, historical evidence from oysters, bluefish and bald eagles indicate that Kepone was present in the James River as early as 1967. Kepone sediment contamination of Chesapeake Bay is not evident.

- Following a 10 year period of Kepone contamination in the James River, sediment samples collected by VIMS from twelve stations in the lower Chesapeake Bay in September 1977 contained no detectable amounts of Kepone.

- In a report submitted to EPA by VIMS in November 1977, it was concluded that: Most Kepone concentrations are located in and above the null zone and they persist with time, both over the short term (8 months of sampling) and over the long term as demonstrated from distribution at depth with cores.

- Male Blue crabs with Kepone concentrations above the FDA Action Level of 0.4 ug/g (ppm) have been found in Chesapeake Bay, but are believed to have migrated into the Bay from the James River. Finfish in Chesapeake Bay have exhibited Kepone concentrations but not above the FDA Action Levels.

- Predictive modeling, simulating a variety of flow rates, and supportive field sampling data from the past 10 years involving two major storms, indicate that the Kepone will remain predominantly situated in the James River sediments upstream from Burwell Bay in the zone of Turbidity Maximum. However, such modeling results and field data could be influenced by major coastal storms and like events and could alter predictions.

Chesapeake Bay Recommendations

- Continued systematic monitoring of Kepone levels in water, sediment, and biota should be conducted in the Chesapeake Bay by the States of Virginia and Maryland to provide warning of unexpected movements of Kepone contamination into Chesapeake Bay.

- A long-term strategy should be developed for the expeditious implementation of emergency mitigation measures for the possibility of unexpected movement of Kepone contamination. The strategy should include engineering studies, such as investigation of the use of submerged silt dams for the containment of Kepone movement from the lower James River, assessment of the feasibility of rapid, large-scale dredging operations, and an integrated development program for assessment of technologies previously described.

Hopewell Area Findings

- Kepone residuals persist in the Hopewell soil areas. Estimates of such surface soil residuals range from 45kg(99lb)to 450 kg (990 lb) of Kepone.

- Kepone concentrations in the soil are highest in the vicinity of the former Life Science Products plant and diminish with distance from the site. The highest Kepone surface concentrations ranged from 9.5 ug/g (ppm) to 1,530 ug/g at the former Life Science Products plant, from 9.2 ug/g (ppm) to 770 ug/g in Nitrogen Park, from 1 ug/g (ppm) to 940 ug/g in the Station Street neighborhood, and from 0.01 ug/g (ppm) to 1,860 ug/g (subsurface) at the Pebbled Ammonium Nitrate site.

- Human health effects have not been determined for Kepone dispersion by soil or air transfer.

- An estimated 1,363 kg (3,000 lb) of Kepone is in the top four inches of a Bailey Creek marsh adjacent to the southeast portion of the Hopewell landfill. The marsh encompasses approximately one-fourth acre.

- The Kepone/sludge lagoon, which contains an estimated 100 kg (220 lb) of Kepone, may be leaking and discharging Kepone into Bailey Creek.

- A small amount (6 grams/day average) of Kepone is routed from the Hopewell primary sewage treatment plant to the Regional sewage treatment plant.

- Runoff from the Hopewell area is estimated to contain 3.3 grams per day of Kepone under low flow conditions and 64 grams per day under storm flow conditions.

- No other significant amounts of Kepone were found in the Hopewell soil areas, including domestic groundwater sources.

Hopewell Area Recommendations

- Potential health impacts in areas of elevated Kepone contamination should be investigated.

- Final disposal of the contaminated material through incineration or other appropriate means in the Kepone/sludge lagoon should be expedited. If disposal action is delayed, it is recommended that all runoff and precipitation be prevented from entering the lagoon.

- Action should be initiated to eliminate or contain the Kepone from the concentrated source in the southeast portion of the Hopewell landfill and the adjacent marsh.

Research Recommendations

Research actions should concentrate on developing appropriate mitigation technologies including retrievable and non-retrievable sorbents, molten sulfur sludge fixation, electron beam and gamma radiation, and amine photodegradation treatment.

Additional research should be undertaken to more fully evaluate impacts of Kepone on the important commercial and recreational species of fish and shellfish in the James River.

I. PROBLEM PERSPECTIVE

PROBLEM OCCURRENCE

Kepone is a registered trade name for the decachloro-octahydro-1,3,4-metheno-2H-cyclobuta(cd) pentalen-2-one member of the cyclodiene family of insecticides. It was developed by Allied Chemical Company* in the early 1950's to control ants and roaches. Most of the production was exported for use in Carribbean and Central American banana fields, and in other countries for control of potato beetles.

Kepone was produced since the 1950's at two places in the eastern United States: State College, Pennsylvania, and Hopewell, Virginia. Releases of Kepone into the environment have occurred at both locations. This report results from a study of the Hopewell, Virginia area.

Kepone was produced at Hopewell, Virginia by Allied Chemical from 1966 to 1974, when the Life Science Products Company,** continued Kepone production under contract to Allied (Exhibits I-1 and I-2). Life Science Products, closed after an investigation by State of Virginia Public Health officials in July 1975 when workers were

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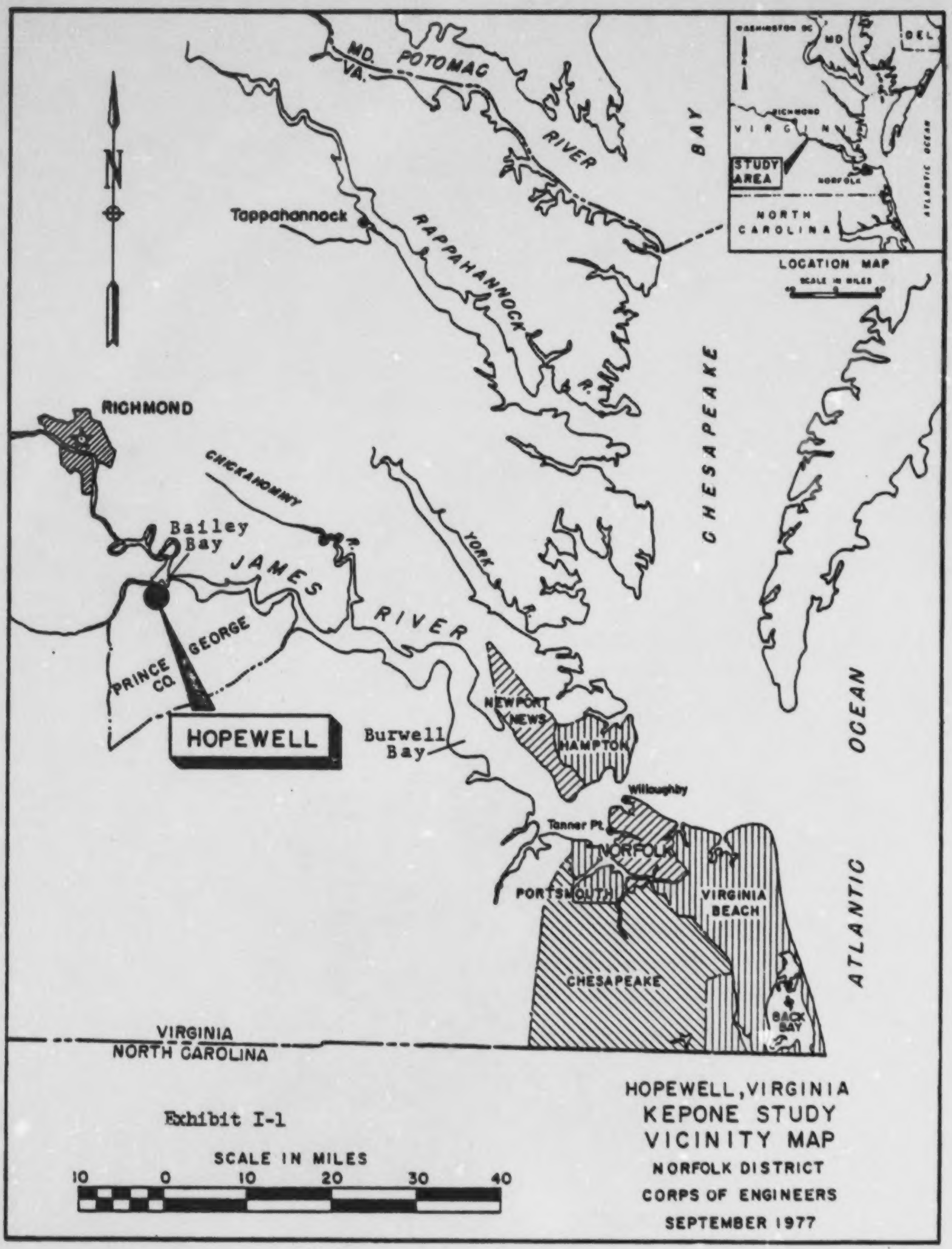
*Referred to hereafter as Allied Chemical
**Referred to hereafter as Life Science Products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POTOMAC
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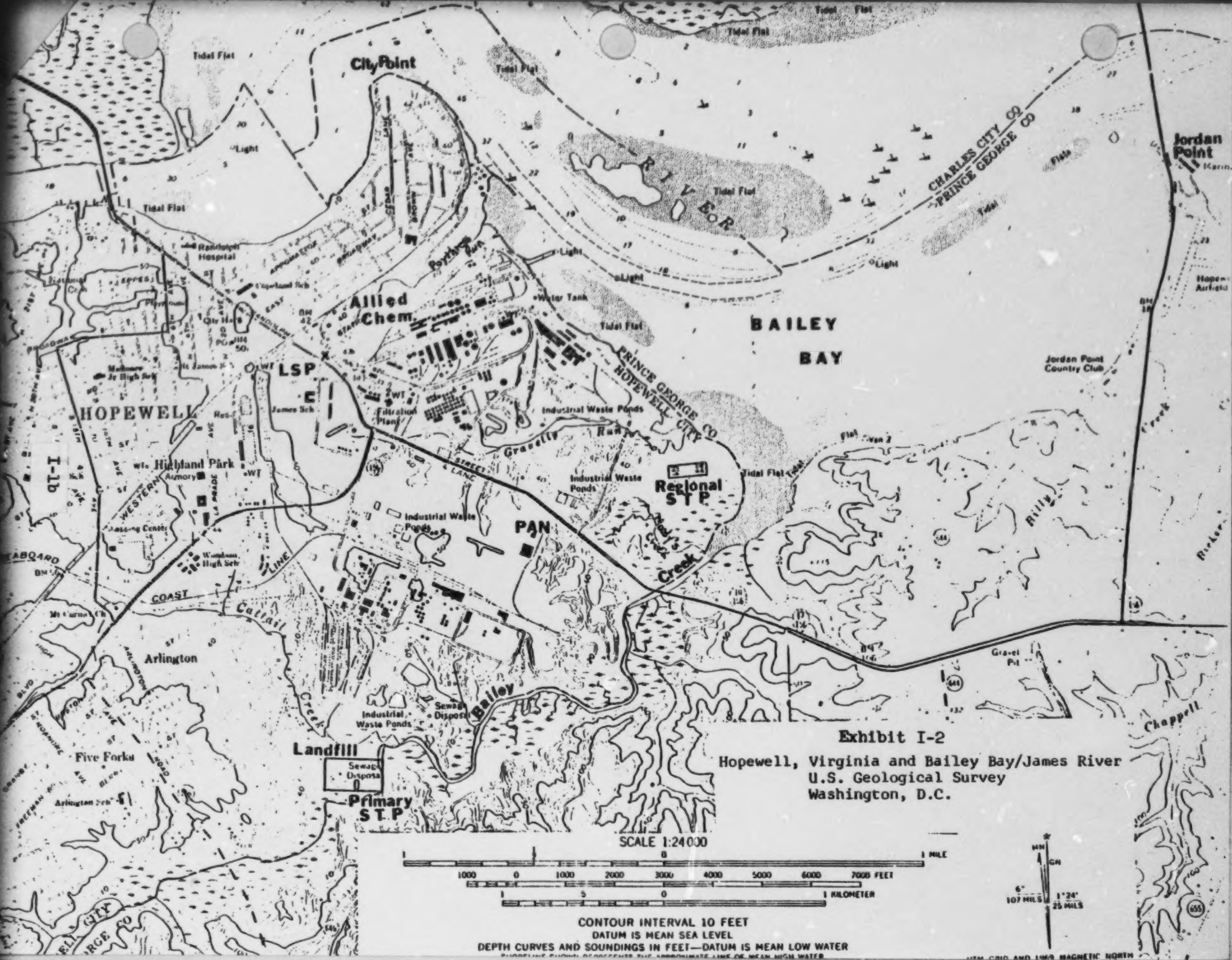
YORK
R.
Bailey
Bay
JAMES
RIVER
PRINCE GEORGE
CO.
HOPEWELL
Burwell
Bay
NEWPORT NEWS
HAMPTON
Willoughby
Tanner Pt.
NORFOLK
PORTSMOUTH
VIRGINIA
BEACH
CHESAPEAKE
BACK BAY
CHESAPEAKE
ATLANTIC
OCEAN
VIRGINIA
NORTH CAROLINA
WASHINGTON DC
MD
DEL
RICHMOND
VIRGINIA
STUDY AREA
NORFOLK
NORTH CAROLINA
ATLANTIC OCEAN
LOCATION MAP
SCALE IN MILES
SCALE IN MILES
10
0
10
20
30
40

Exhibit I-1

HOPEWELL, VIRGINIA
KEPONE STUDY
VICINITY MAP
NORFOLK DISTRICT
CORPS OF ENGINEERS
SEPTEMBER 1977


City Point
Tidal Flat
Light
RIVER
CHARLES CITY CO
PRINCE GEORGE CO
Jordan Point
Hopewell Airfield
BAILEY BAY
Jordan Point Country Club
Hospital
Allied Chem.
Water Tank
PRINCE GEORGE CO
HOPEWELL CITY
LSP
HOPEWELL
Filtration Plant
Industrial Waste Ponds
Gravelly Run
Highland Park
Armory
Regional STP
PAN
Bailey Creek
SEABOARD
COAST LINE
WESTERN
Cattail Creek
Arlington
Five Forks
Arlington Sch
Industrial Waste Ponds
Sewage Disposal
Bailey Creek
Landfill
Primary STP
Gravel Pit
Chappell Creek
Sewage Disposal
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
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GN
6°
107 MILS
1°24'
25 MILS
UTM GRID AND 1969 MAGNETIC NORTH

Exhibit I-2

Hopewell, Virginia and Bailey Bay/James River
U.S. Geological Survey
Washington, D.C.

diagnosed to have Kepone poisoning. More than 70 individuals developed ailments ranging from slurred speech, loss of memory, irritability and sleeplessness, to liver damage and sterility. At the present time, all but a few such individuals have recovered and no longer show symptoms.

CHRONOLOGY

Listed below is a chronology of relevant events associated with the Kepone problem at Hopewell. The events and dates are taken from various proceedings, including the Senate Subcommittee Hearings on Kepone Contamination in January 1976 (Senate Hearings, 1976), the Council on Environmental Quality (CEQ, 1976) and other Federal and State documents. The Senate Hearings and the CEQ Report have been chosen as the prime sources, since the exact dates of certain events varied between the several documents used.

1966 - March 1974	Intermittent manufacture of Kepone by Allied Chemical occurred at its Semi-Works plant in Hopewell, Virginia.
October 1973	Life Science Products applied to the Virginia State Water Control Board for

	permit to discharge sanitary wastewaters into the Hopewell sewage treatment plant.* The application claimed no industrial discharges would enter the Hopewell treatment plant.
November 1973	Life Science Products signed an agreement with Allied Chemical to produce Kepone on a toll processing contract basis.
February 1974	Life Science Products began production of Kepone. Malfunctions of production equipment allowed the release of sulfur trioxide to the atmosphere. The Virginia Air Pollution Control Board cited Life Science Products for failure to obtain an air permit.
October 1974	A bag-filter collector was installed at the Life Science Products plant.
	During survey of the Hopewell treatment plant, the Virginia Water Control Board

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*Referred to hereafter as the Hopewell treatment plant discovered the plant's digester was operating improperly. Kepone was being discharged into the city's sewage system. A meeting to discuss the matter was attended by staff members of the City of Hopewell, the Virginia State Water Control Board, the Virginia Department of Health, and Life Science Products. Staff of the Board stated that the levels of Kepone discharged to the Hopewell treatment plant must be drastically reduced.

November 1974	The Virginia Water Control Board developed an effluent limitation of 0.4 parts per billion for Kepone discharges into the municipal system. Life Science Products agreed to implement a continuous monitoring system in order to establish those levels of Kepone to protect the integrity of the Hopewell treatment plant.

December 1974	The staffs of the Virginia Department of Health and State Water Control Board met with representatives of the City of Hopewell and Life Science Products. Further pretreatment of wastewater discharged by the company would be required to meet the limitation of 0.017 pounds Kepone per day in the Hopewell treatment plant effluent.
April 9, 1975	The staff of the Virginia Water Control Board recommended amendments to the Hopewell National Pollutant Discharge Elimination System (NPDES) permit. These amendments provided for limitations on Kepone in the Hopewell treatment plant effluent of 1.0 ug/l (ppb) maximum instantaneous concentration, 0.5 ug/l (ppb) daily average, and 7.59 g/day (0.017 lb/day) daily maximum. The amendments also contained the condition that the City of Hopewell require Life Science Products to pretreat Kepone to a level of 100 ug/l (ppb), effective June 6, 1975.

April 1975	The City of Hopewell began construction of an asphalt-lined lagoon to contain Kepone-contaminated sewage sludge from the Hopewell treatment plant.
July 11, 1975	The Atlanta Center for Disease Control received a blood specimen of a Life Science Products worker. Analysis revealed a 7.4 ug/g (parts per million) level of Kepone.
July 23, 1975	Virginia health officials conducted an inspection of the Life Science Products' operations and examined 10 employees working in the plant. Seven of the employees had symptoms of neurological illnesses. Several had symptoms severe enough to require hospitalization. Plant inspection revealed building, air, and ground contamination by Kepone.
July 24, 1975	Life Science Products management agreed to close the plant and comply voluntarily with all the conditions of the Virginia Health Department.

July 25, 1975	Virginia State Health Department ordered Life Science Products to stop production. However, limited production continued into September.
August 19, 1975	The U.S. Occupational Safety and Health Administration (OSHA) first visited Hopewell where Kepone production continued despite the State order to close. OSHA issued citations to Life Science Products for four violations of the OSHA Act of 1970, including failure to prevent employee exposure to harmful levels of Kepone. Fines totalling $16,500 were proposed.
August 20, 1975	The U.S. Environmental Protection Agency issued an order to Life Science Products under the authority of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) to stop the sale or use of Kepone, as well as to prevent its removal from the premises.

September 9, 1975	An Ad Hoc Committee, consisting of members of the State Water Control Board, State Health Department and the City of Hopewell was established to determine methods and costs involved in cleaning up the Life Science Products plant site and disposing of any waste materials.
November 20, 1975	State Health Department submitted oyster, sediment and fish samples from the lower James River for analysis of Kepone content to EPA at Research Triangle Park, North Carolina.
December 5, 1975	An interagency Kepone Task Force was established by the Commonwealth of Virginia to coordinate all State activities related to Kepone. The State Department of Health was chosen as the lead Agency.
December 18, 1975	Governor Mills E. Godwin, Jr., of Virginia, closed the entire James River and its tributaries from Hopewell to the Chesapeake Bay for the taking of

	shellfish and finfish until July 1, 1976, or until such time as the order might be rescinded.
February 3, 1976	The EPA recommended to the Food and Drug Administration an Action Level* of 0.3 ppm in shellfish and the removal from the market of any Kepone-contaminated shellfish exceeding this level.
February 25, 1976	The EPA recommended to the Food and Drug Administration an Action Level of 0.1 ppm in the edible portion of finfish.
May 7, 1976	A Federal grand jury indicted Allied Chemical, Life Science Products, the City of Hopewell, and several individuals of 1,097 counts for violating Federal anti-pollution laws.

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*Action Level is the allowable level of residue of the substance (Kepone). The level is used as an enforcement guide.

August 19, 1976	Allied Chemical pleaded no contest to 940 criminal charges and was convicted of discharging Kepone wastes into the James River.
August 25, 1976	The EPA Administrator designated a Kepone Coordinator for the Agency and for an EPA Headquarters/Region III working group.
August 26, 1976	The Federal/State Kepone Task Force recommended a Kepone mitigation feasibility project.
August 30, 1976	The Governors of Virginia and Maryland requested the EPA Administrator to undertake a mitigation feasibility project on the Hopewell, Virginia/James River Kepone contamination problem.
September 1976	The EPA recommended to the Food and Drug Administration an Action Level of 0.4 ppm in crabs.

September 2, 1976	The EPA Administrator announced EPA's intent to undertake a Kepone mitigation feasibility project. Actions were initiated to develop a project plan and establish funding.
October 5, 1976	Allied Chemical was fined $13.24 million by Judge Robert Merhige on its no contest plea of 940 pollution counts. The fine later was reduced to $5.24 million when Allied agreed to give $8 million to establish the Virginia Environmental Endowment.
October 11, 1976	First Kepone Seminar was held at Gloucester Point, Virginia.
Early 1977	A Kepone incineration test program was conducted, which demonstrated that Kepone could be incinerated in a safe and effective manner.

March 17, 1977	Following a series of hearings, the Federal Food and Drug Administration adopted an Action Level for Kepone in finfish of 0.3 ppm.
March 31, 1977	EPA Headquarters initiated the Kepone Mitigation Feasibility Project with support funding of $1.4 million.
July 6, 1977	The Virginia Health Department signed a contract with Flood & Associates, Inc., of Virginia, to conduct a design study that would culminate in a facility plan to suggest methods to dispose of Kepone-contaminated wastes stored in Hopewell.
August 31, 1977	The first public meeting on the initial screening of alternatives for the ultimate disposal of Kepone-contaminated wastes stored in Hopewell was held in Hopewell.

September 18, 1977	Governor Godwin of Virginia closed part of the lower Chesapeake Bay to the harvesting of male blue crabs.
September 19, 1977	The second Kepone Seminar was held at Easton, Maryland.
October 1977	The State of Virginia agreed to a partial settlement with Allied Chemical for $5.25 million.
October 18, 1977	The second public meeting was held at Hopewell at which the final alternatives to be evaluated in a facility plan for the ultimate disposal of Kepone-contaminated wastes stored in Hopewell were presented.
December 30, 1977	Governor Godwin extended the fishing ban order for the James River for one year.
February 8, 1978	Draft report of EPA Kepone Mitigation Feasibility Project was distributed for technical review.

In August 1975, the State of Virginia asked the EPA Health Effects Research Laboratory in North Carolina to institute a human and environmental sampling program to ascertain the extent and effects of Kepone contamination. EPA reported its results on December 16, 1975. Blood and sebum skin samples from 28 hospitalized Life Science Products workers and one worker's wife contained Kepone residues ranging from 0.2 to 7.5 ug/g (ppm). Kepone was found in the James River water samples at concentrations of 0.1 to 14 ug/g (ppm). Some of the water and shellfish samples were collected 40 and 64 miles downstream from Hopewell, respectively (EPA, 1975). Sewage sludge and James River sediments contained significant Kepone concentrations.

As a result of Kepone contamination, the Governor of Virginia closed the James River to fishing on December 18, 1975. Restrictions were placed on the taking of fish, shellfish and crabs from the James River. The river, which enters the lower Chesapeake Bay, had supported the livelihood of many watermen and other individuals in fishery-related activities. Thus, the Kepone restrictions have had, and continue to have an adverse effect upon the economy of the region.

KEPONE PRODUCTION AND ROUTES

Allied Chemical's Semi-Works plant was a flexible facility used to produce specialty or small volume products. As noted previously, it produced Kepone intermittently from 1966 to 1974. Life Science Products began production of Kepone in early 1974, soon after Allied Chemical ceased its Kepone production. The company was formed by an agreement with Allied Chemical, whereby Allied Chemical supplied raw materials to Life Science Products, paying a prearranged price for the Kepone product. Exhibit I-3 shows the amount of Kepone estimated by Ferguson (1975) to have been produced by Allied Chemical and Life Science Products.

The Kepone losses from Life Science Products were principally from four basic sources: (1) atmospheric releases from drying and bagging operations; (2) routine daily wastewater discharges; (3) releases to the sewer from spills, malfunctions, and bad batches; and (4) bulk liquid and solid waste loads discharged to the terrestrial sites around Hopewell.

Estimates of the Kepone losses from Life Science Products and the Allied Chemical's Semi-Works plants are difficult to calculate because of the limited amount of information available. However, James River oyster samples from 1967 to 1970 exhibited Kepone concentrations as high as 0.21 ug/g (ppm) (Oswald, 1976). Bluefish, menhaden and spot

Exhibit I-3

Production Levels of Kepone from Allied Chemical's Semi-Works Plant

Year	Production	
	kg	lb
1966	35,935	78,125
1967	47,990	105,800
1968	36,535	80,550
1969	46,990	103,600
1970	41,460	91,400
1971	204,800	451,515
1972	176,970	390,150
1973	100,435	221,425
1974	72,260	159,300
Total	762,875	1,681,865

Production Levels of Kepone from Life Science Products

Year	Production	
	kg	lb
1974	385,370	849,600
1975	384,020	846,625
Total	769,390	1,696,225

fish samples from 1973 also showed Kepone concentrations in the flesh as high as 0.62 ug/g (ppm) (SWCB, 1973). In addition, U.S. Fish and Wildlife Service samples of Chesapeake Bay area bald eagles from 1970 to 1972 exhibited Kepone in livers as high as 83 ug/g (ppm) (U.S. Fish and Wildlife Service, 1977).

KEPONE ROUTES TO THE ATMOSPHERE

Production at the Life Science Products plant resulted in significant releases of particulate Kepone into the atmosphere. During the period of operation, complaints were received on these particulate emissions. The complaints led to State of Virginia action requiring installation of a bag-filter house in October 1974. Subsequent analysis of preserved filters from State-operated air sampling stations revealed contamination of particulate matter to be as much as 40 percent Kepone. Detectable levels of Kepone were measured at distances of 25 km (16 mi) from Hopewell. An air monitoring station was about 200 yards from the Life Science Products plant. From these air filters, calculations indicated Kepone levels would have been between 0.2 to 50 ug/m^3 of air during the period of March 1974 to April 1975 (EPA, 1975).

Monitoring of air in the Hopewell area after the Life Science Products closure revealed a decline in Kepone concentrations to nondetectable levels. Consequently, it can be assumed that the atmosphere held Kepone only for a short period and the air should not be considered a major reservoir for Kepone.

KEPONE ROUTES TO THE SEWER SYSTEM

Wastewater from Life Science Products passed through the Station Street pumphouse to the Hopewell treatment plant where it was treated and discharged to Bailey Creek. Analysis of samples revealed that wastewater discharges from the Life Science Products plant contained Kepone up to 36.9 mg/l (ppm). Analysis of one of the digesters at the sewage treatment plant revealed a level of 68 mg/l (ppm) in digester sludge (Senate Hearings, 1976).

Initially, the sewage sludge was disposed in the city's sanitary landfill. However, after concern developed over contamination by the sludge, it was decided to contain the sludge to prevent leaching of Kepone. In May 1975, a Kepone/sludge lagoon was completed on the grounds of the Hopewell treatment plant (see Exhibit I-2), and the digester sludge was placed in it. The lagoon holds approximately 4,140 cubic meters (1.1 million gallons) of sludge. Sludge samples taken from the Kepone/sludge lagoon and from the Hopewell sanitary landfill contained 598 and 189 ug/g (ppm) Kepone (EPA, 1975). The remains of the dismantled Life Science Products plant is in another clay and PVC-lined pit at the Hopewell sanitary landfill.

Effluent levels of Kepone from the Hopewell treatment plant have been monitored since 1976 on a weekly, and at present, on a monthly basis. The Kepone concentrations have ranged from 0.04 to 5.26 ug/l (ppb). In July 1977, Kepone levels rose to 5.26 ug/l (ppb) and have often stayed above 0.5 ug/l (ppb) through much of 1977.

HEALTH EFFECTS

Production workers at Life Science Products were the most severely affected individuals from their exposure to Kepone. Production personnel exhibited a symptoms rate of 64 percent with an average latent period of six weeks. Generally, non-production persons, who were exposed less directly to Kepone, were less affected by the symptoms of Kepone poisoning (16 percent) (Cannon, et al., in press). However, there were also exposures to the Hopewell populace to Kepone near the Life Science Products plant when Kepone was produced.

Seventy-six Life Science Products personnel contracted a previously unrecognized clinical illness characterized by nervousness, tremor, bursts of rapid eye movement (opsoclonus), weight loss, and pleuristic and joint pain. Other symptoms included ataxia, skin rash, sterility, liver enlargement and abnormal liver functioning. The relative blood concentration of Kepone workers with the illness was 2.53 ug/g (ppm), while workers without the illness averaged 0.60 ug/g (ppm). Residents and other workers within a mile of the Life Science Products plant had blood levels ranging from undetectable to 32.5 ng/g (ppb) (Cannon, et al., in press).

Physicians at the Medical College of Virginia, in recent work with Life Science Products workers, have developed a method which reduces Kepone by fecal excretion an average of seven times the natural rate. Kepone output in the bile was 10 to 20 times greater than in the feces, suggesting that Kepone was being reabsorbed by the intestine. Cholestyramine, an anion-exchange resin, was found to bind Kepone and allowed accelerated elimination of Kepone from the workers' bodies involved in this program. After completion of the trial, all patients were given cholestyramine, and six months later, blood levels were undetectable in 12 of 22 patients and none were judged to have more than "mild" neurologic signs (Cohn, et al., 1978).

Kepone has been tested under the auspices of the National Cancer Institute (1976). Osborne-Mendel rats and B6C3F1 mice, fed Kepone in their diets at two dose levels for 80 weeks, developed a significant increase in liver tumors (hepatocellular carcinomas) in the high-dose-level rats and at both dose levels for mice. Some controversy has surrounded the NCI study concerning the experimental methodology and the identification of the tumors. A new joint study between NCI and the National Institute of Environmental Health (NIEH) is being developed. The human carcinogenicity risk associated with Kepone at the level found in the Life Science Products workers will be assessed. Starting about October 1978, NIEH will examine dose/response relationships in subchronic studies on tremor, memory loss, sterility and other adverse Kepone effects. From this information NCI will perform chronic toxicity studies to project threshold levels which could be carcinogenic. The entire program is anticipated to last three years.

ACTION LEVEL DETERMINATION

In February 1976, EPA recommended "Action Levels" to the Food and Drug Administration (FDA) of 0.3 ug/g (ppm) in the edible portion of shellfish (oysters and clams), 0.1 ug/g (ppm) in finfish, and 0.4 ug/g (ppm) in crabs. EPA also recommended a 0.3 ug/g (ppm) Action Level in processed oyster stew. These recommendations were made using classical estimating procedures for threshold effects. At that time, EPA committed itself to further consideration of this Action Level for possible revision if new data warranted it. EPA revised its recommendations in early 1977. Revised Action Levels are 0.3 ug/g (ppm) for fish and shellfish and 0.4 ug/g (ppm) for crabs. The January 1, 1978 Emergency Rule of the State of Virginia for the James River allows the taking of catfish, shad, herring, baby eels and turtles. The harvesting of blue crabs is permitted only in certain parts of the river and only under certain conditions.

LITIGATION AND REGISTRATION ACTIONS

Criminal indictments were brought against Allied Chemical Life Science Products and the City of Hopewell, Virginia. In addition, criminal actions were brought against individual employees of both companies. In two trials, Allied Chemical was convicted on 940 counts for violation of the Federal Water Pollution Control Act Amendments of 1972 and the Rivers and Harbors Act of 1899 ("the Refuse Act"), with an imposed fine of approximately $13.24 million. Life Science Products was convicted on 153 counts and fined approximately $3.8 million. The City of Hopewell pleaded guilty, was fined $10,000, and was placed on five years probation (Whitman, 1977).

Criminal suits were brought against the president and vice-president of Life Science Products and against four employees of Allied Chemical. The president and vice-president were convicted and each fined $25,000 and placed on five years probation. Several individuals pleaded "nolo contendere" to reduced charges (misdemeanors) in return for dismissal of the felony conspiracy charges. Two defendants were acquitted before U.S. District Court Judge Robert R. Merhige, Jr. The Department of Justice determined that sentencing of the other individuals for the same conduct would be unjust, therefore, charges were dismissed against the remaining defendants. Allied Chemical's $13.24 million fine was reduced to $5 million with the establishment of the Virginia Environmental

Endowment financed with $8 million of Allied Chemical's money (Whitman, 1977).

Suits brought by individual workers of Life Science Products against Allied Chemical have been settled out of court. Less than five workers' suits remain unresolved. The State of Virginia recently has settled part of its claims against Allied Chemical for $5.25 million. The State reserves the right to sue Allied Chemical for cleanup of the James River, and disposal of stored Kepone residuals.

Allied Chemical is being sued in a Class Action Suit (Pruitt vs. Allied Chemical Corp.) on behalf of all the people in the Chesapeake Bay region who have lost income because of the Kepone incident. In addition, there are two watermen suits (Adams and Ferguson). Their suits against Allied Chemical are for loss of fishing from the closed James River.

In an agreement with Allied Chemical, EPA has cancelled technical and manufacturing use registrations of Kepone (Federal Register, 1976). Some pesticide formulators were permitted to utilize small percentages of Kepone in inaccessible ant and roach traps until stocks were used or until May 1, 1978, whichever came first (Federal Register, 1977).

II. PROBLEM RESPONSES

EPA, STATE, AND LOCAL EFFORTS

The Kepone-related problems which Virginia encountered prompted Governor Mills E. Godwin, Jr. to establish a coordinated effort to deal with the issue. At the direction of the Governor, Mr. Otis L. Brown, Secretary of Human Affairs, and Mr. Earl J. Shiflet, Secretary of Commerce and Resources, established the interagency Kepone Task Force on December 5, 1975. The State Department of Health was assigned the role of lead Agency and Dr. James B. Kenley, then Deputy Commissioner of Health, now Commissioner of Health, was appointed the Chairman of the Kepone Task Force. The Kepone Task Force was charged with the responsibility for coordinating the comprehensive efforts by relevant State agencies and organizations in dealing with the problem of Kepone. Subsequently, EPA established an internal task force to work with State and other Federal agencies to offer technical assistance and research support. Other Virginia State agencies and organizations which provided representation to the Virginia Kepone Task Force included: Air Pollution Control Board; Attorney General's Office; Division of Consolidated Laboratory Services; Department of Labor and Industry; Virginia Commonwealth University/Health Sciences Division; and State Water Control Board.

Subsequent to the initial organization of the Virginia Kepone Task Force, other State agencies and groups assumed responsible roles in the Task Force. These included: the Virginia Council on Environment; Department of Agriculture and Commerce; Virginia Institute of Marine Science; Virginia Polytechnic Institute and State University; Marine Resources Commission; and the Office of Emergency Services.

To supplement the Virginia Kepone Task Force expertise, assistance was solicited from numerous Federal agencies and private organizations, including the Environmental Protection Agency, Federal Food and Drug Administration, Center for Disease Control in Atlanta, and Occupational Safety and Health Administration.

The major problem areas, which confronted the Virginia Task Force at the time of its establishment, some of which persist today, included: cleanup of Life Science Products facilities in Hopewell; cleanup and disposal of wastes located at the Hopewell primary sewage treatment plant; epidemiological studies; marine studies; cleanup of the James River; and assessment of the economic impact of closing the James River.

In December of 1975, the Virginia State Water Control Board developed a long range program for monitoring the contamination in the James River. This program was initiated in January 1976 and has involved extensive water and a sediment sampling and a fish sampling program with the Virginia Institute of Marine Science. Forty-eight locations for water and sediment sampling were designated, ranging from the discharge area at the Hopewell primary treatment plant to the Hampton Roads Bridge Tunnel. Seven zones were defined in the fish sampling plan, extending from Hopewell to Chesapeake Bay. The continuing comprehensive sampling program of the Virginia Water Control Board has been invaluable for its guidance in the design of complementary sampling efforts for EPA's Kepone Mitigation Feasibility Project.

Concurrently with the development and implementation of the Virginia Water Control Board's Kepone monitoring program, Virginia's Division of Consolidated Laboratory Services, with assistance of Allied Chemical, developed and implemented protocols and the analytical methods for determining the quantity of Kepone residing in the air, water, soil, sediment and biota. Specific protocols were developed for determination of Kepone in:

1. Shellfish and Fish
2. Dairy Products, Eggs, and Feeds
3. Vegetables, Fruit, and Juices
4. Air Filters, Wall Wipes, and Vacuum Dust Bags
5. Water
6. Sediment and Soils

The protocols are used in the State of Virginia's market sampling and seed oyster sampling programs as well as the other continuing Kepone monitoring programs.

While the immediate impact of the Kepone contamination necessitated a large scale Kepone-related effort in the State of Virginia, the State of Maryland also initiated efforts to continue to assess potential impacts of Kepone in Maryland by appointing a multi-agency, multi-disciplined State Task Force. Its efforts guided Allied Chemical in their containment and safe storage of Kepone material located at an Allied Chemical facility in Baltimore. In 1975, residents near the Baltimore Allied Chemical plant were screened for Kepone. No detectable amounts of Kepone were found. A playing field next to the Allied facility showed 10 ug/g (ppm) Kepone levels along a common fence. The park was closed, the land stripped, and resodded with uncontaminated soil.

The Maryland Task Force also initiated efforts to sample Chesapeake Bay for Kepone. In the Bay, oyster bars with seed oysters transplanted from the James River were tested for Kepone. There were varying amounts of Kepone from low to non-detectable with only one oyster bar near the mouth of the West River having concentrations exceeding the FDA Action Levels. The single oyster bar was closed and reopened a year later when Kepone was not detected. Blue crabs were sampled on the Maryland side of Chesapeake Bay, but Kepone concentrations were below the FDA Action Levels. Likewise, bluefish showed low levels of Kepone. Kepone was not detected in the sediments. At present, the State of Maryland has a continuing market sampling program for Kepone and the Maryland State Health Department requires Virginia to certify that seed oysters are free from Kepone before they can be transplanted to Maryland waters of the Chesapeake Bay.

The need for routine maintenance dredging of the James River for navigational purposes posed an additional problem and requirements to be assessed by a State of Virginia/Corps of Engineers/EPA effort. Dredging of the James might disperse the Kepone contaminants downstream and thus create more widespread contamination and threaten Chesapeake Bay. Accordingly, a test dredging of selected shoal areas was undertaken in July 1976 by the U.S. Corps of Engineers in coordination with EPA and the Virginia Water Control Board. Monitoring of the test dredge operation indicated that increased water and sediment contamination by such dredging were confined to the areas of dredging. Dredging with disposal in the river near the channel is now examined on a case by case basis by the Commonwealth of Virginia, which may then issue a Water Quality Certificate. In addition, a U.S. Corps of Engineers Section 404 permit is required.

REQUEST FOR AN EPA MITIGATION FEASIBILITY PROJECT

The results of the initial efforts to assess the nature and extent of Kepone contamination in the Hopewell-James River areas indicated a pervasive and critical problem. Accordingly, on August 26, 1976 the Federal/State Kepone Task Force recommended that a feasibility study be undertaken to evaluate dredging or other means to mitigate Kepone effects in the James River. Based on this recommendation, Virginia's Governor Godwin and Maryland's Governor Mandel issued a joint request on August 30, 1976 to the Administrator of EPA to undertake a feasibility study. While requesting an analysis of dredging or other means of containing the Kepone contamination, the Governors cautioned: "While current research indicates dredging may be an alternative, the impact on downstream aquatic life, the degree of reduction of contamination, the cost involved, the problems of spoil disposal, and long term effect on the River need to be determined before any intelligent decision can be made as to the impact of dredging on the River."

GUIDELINES ESTABLISHED FOR EPA MITIGATION FEASIBILITY PROJECT

In response to the Governor's request, the Administrator of EPA announced his intent on September 2, 1976 to initiate a feasibility study. As reflected in the caution of the Governors' request to EPA, it was immediately apparent that a much more thorough data acquisition and analysis effort would be required to provide a basis for assessing the problem and exploring mitigation measures for the Hopewell/James River areas. Accordingly, a series of approaches were developed which evolved into a two-phased project plan proposed in November 1976. Phase I, the subject of this report, involved a detailed assessment of: suspected continuing sources of Kepone contamination; fate and transport of Kepone in the James River system; current and long-range effects of Kepone contamination on the biota; and evaluation of mitigation and removal methods. The results of Phase I are to provide a basis for action recommendations. Following review of the recommendations by EPA and the States of Virginia and Maryland, Phase II might involve a decision to: seek funding for a major cleanup or mitigation program; proceed with pilot testing of alternative corrective and mitigative actions; or withhold further action.

III. DESCRIPTION OF PROJECT AREA

The area under investigation, as shown on Exhibits I-1 and I-2 is the City of Hopewell, Prince George County, and the James River from Hopewell to Chesapeake Bay.

HOPEWELL AND PRINCE GEORGE COUNTY

Physical Features

As indicated in Exhibit I-1, Hopewell and Prince George County lie entirely in the coastal plain of Virginia and encompass about 11 and 276 square miles, respectively. The topography at Hopewell generally is hilly with steep streambanks in the vicinity of Bailey Creek and Gravelly Run, with elevations ranging from near sea level to approximately 130 feet above sea level. Slopes in the Prince George County portion of the study area can approach 40 to 50 percent in some steeper areas. In the City of Hopewell, slopes generally are more gradual and amenable to the development that has occurred. Temperatures in the area average 27 degrees C (80 degrees F) in July and 4.5 degrees C (40 degrees F) in January, with precipitation averaging approximately 40 inches per year.

In 1913, Hopewell developed from a population of about 300 people into a boom town after the completion of a dynamite plant by the

DuPont de Nemours Company. With the beginning of World War I, the factory was converted for the production of gun cotton and was making more than one million pounds a day until the end of the War. The population of Hopewell was estimated to be approximately 40,000 during this period, with 15,000 to 20,000 people working at the factory. With the end of World War I and the closing of the DuPont factory, people left Hopewell as rapidly as they had come. By 1920, the census showed a city population of only 1,320. However, during the next decade, the population began to increase again as new industries moved to the area formerly occupied by DuPont's gun cotton plant.

One company to locate in Hopewell after World War I was Hercules Powder Company. The principal product was explosives, but they also manufactured film, lacquers, and material for rayon, transparent cellulose, and stationery. Today, Hercules employs over 1,000 people in the production of plastic materials, synthetic resins, and chlorine industrial inorganic chemicals. Another large industry in Hopewell is the Forest Industries, formerly known as Continental Can Company, which produces liner board and material for corrugated boxes.

In 1928, Allied Chemical and Dye Corporation established a nitrate plant through their subsidiary, the Atmospheric Nitrogen Corporation. In 1954, Allied's National Aniline Division located a fiber operation in Hopewell. The General Chemical Division of Allied Chemical built a small alum plant near Route 10. Currently, Allied Chemical maintains two plants in Hopewell, the Fibers Division and the Industrial Chemicals Division. The Fibers Division manufactures industrial organic chemicals and the Industrial Chemicals Division manufactures alum. Together, these two plants employ approximately 1,150 people.

Firestone located in the city in 1960 and produces nylon and polyester yarns. With approximately 1,500 employees, this company is the largest industrial employer in Hopewell.

Social Background

The populations of both Hopewell and Prince George County have increased since 1950. The most recent estimates indicate that Hopewell had a population of 23,300 and Prince George County had a population of 18,700 as of July 1, 1975 (University of Virginia, 1975). Projections for the area's population through the year 2000 show small but steady increases for both Hopewell and Prince George County.

Manufacturing is the foundation of Hopewell's economy, and it directly provides slightly over 50 percent of the city's jobs. Additional jobs are found in wholesale and retail trade and in government. By contrast, in Prince George County, governmental agencies, primarily Federal, accounted for two-thirds of the employment as of 1972. Income levels for both Hopewell and Prince George County are close to State levels.

Land-Use Patterns and Plans

The Land-Use Plan for Hopewell indicates that 56 percent of the land area in 1970 was developed. The majority was included in the residential and industrial categories. Probably the most important factor influencing the land-use pattern is Hopewell's large industrial complex. This complex has forced residential development westerly away from the James River.

The section of the city bordering the western side of Bailey Creek is currently zoned for heavy industry to just past the Hopewell primary sewage treatment plant and zoned for residential in other parts. Although much of this area zoned residential is vacant, housing construction is currently taking place between the Hopewell treatment plant and Route 156. The county land areas adjacent to Bailey Creek are planned primarily for residential development through the year 2000.

Archeological Resources

At present, little is known concerning the archeological resources of the Hopewell area, although at least five upland archeological sites have been identified by the Virginia Historic Landmarks Commission. Principal sites of archeological or historical significance are Eppes Island, located at the confluence of the James and Appomattox Rivers, and Shirley Plantation, located five miles north of Hopewell.

Environmental Description

Air Quality

Suspended particulates and sulfur dioxides are measured regularly in the Hopewell area by the Virginia State Air Pollution Control Board (SAPCB). Recent tests indicate that sulfur dioxide does not appear to be a problem. For the year ending March 1977, there were no violations of the National Ambient Air Quality Standards noted in the Hopewell area. However, violations for suspended particulates have occurred in the past (SAPCB, 1977).

Odor is also a problem in this area. Odor-causing substances are emitted from the several fiber mills in Hopewell. Also, odors emanate from Bailey Creek and Bailey Bay waters.

Water Quality

The water quality in Bailey Creek and Gravelly Run has been influenced by the effluent from Hopewell's primary treatment plant, industrial outfalls, and cooling water outlets located on these tributaries. The volume of waste entering Bailey Creek and Gravelly Run is the cause for its severe water quality problem. Dissolved oxygen, pH, BOD, TKN, nitrate and orthophosphate vary significantly from the values that would be expected for these types of streams. Additionally, a black plume originating in Bailey Creek and Gravelly Run is normally visible in the James River from the air for at least 5 to 10 miles (8 to 16 kilometers) below Hopewell (NASA, 1977).

In late 1977, the Regional secondary sewage treatment plant* at Hopewell began operation. Evidence of water quality improvement in the project area is expected. The dissolved oxygen, BOD, and pH will be improved, but the exact effect of the plant on the receiving waters cannot be estimated at this time.

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*Hereafter referred to as the Regional treatment plant

Environmental Setting

The land area in Hopewell and vicinity consists of areas that are heavily industrialized, urbanized, and suburbanized. It is composed of agricultural areas, upland woods, wooded swamp, and marsh. Data gathered by the U.S. Fish and Wildlife Service personnel during August 1977 indicate that while the upland and marsh areas appear normal, exclusive of the odor and color of the water and sediments, there are significant differences between the wooded swamps of Bailey Creek and a similar area downriver. The survey made particular note of the absence of fish-eating birds and songbirds in the Bailey Creek area.

Although the new Regional treatment plant should lessen the impact that pollution in Bailey Creek has had on Bailey Bay and the James River, improvement in water quality of Bailey Creek and Gravelly Run will continue to be inhibited by the effects of the polluted sediments in these streambeds.

THE JAMES RIVER

The James River is the largest of Virginia's river systems. Although the James River originates in West Virginia, consideration in this study is limited to the tidally influenced region from Hopewell east to its confluence with the Chesapeake Bay. Most of the study area is flat, rising less than 40 feet above sea level.

The James River is tidal from the falls at Richmond to its mouth, a distance of 153 km (95 mi.). Its width varies from approximately 0.3 km (1/2 mi.) wide near Richmond to approximately 8 km (5 mi.) wide near its mouth. The tidal portion of the river has four main tributaries: the Appomattox, the Chickahominy, the Nansemond, and the Elizabeth Rivers. The flow in the James River at Richmond has varied from 8,863.17 cubic meters per second (cms) to 9.06 cms with the average flow being 212.38 cms.

Lands adjoining the river are fertile agricultural tracts, forested upland and bottomland, and marshes and swamps that afford high value habitat for migratory waterfowl, other birds, game and fur animals. Hunting and fishing are important recreational pursuits along the tidal section of the James. There are numerous privately owned hunting and fishing camps and two public wildlife refuges in the area. The Virginia Commission of Game and Inland Fisheries maintains a 2,100 acre waterfowl refuge on Hog Island and the U.S. Fish and Wildlife Service maintains Presquile National Wildlife Refuge, a 1,329 acre refuge on Turkey Island upstream of Hopewell.

The only major population area along the River downstream from Hopewell is at the mouth of the river where Newport News, Hampton, Portsmouth, and Norfolk form the Hampton Roads Area.

The tidal portion of the James River is sluggish and is characterized by a sandy/silty bottom. Both fresh and salt water species are typically found in the James River with the species found according to their salinity regimes. The tidal James River has long been utilized for commercial and sport fishing. Fishery resources are diverse and productive. The river contains freshwater and marine fish, including many migratory species. The commercial fishing grounds extend from upstream of the Hopewell area to the mouth of the James River. The freshwater and upper portion of brackish water zones are extensively used as spawning and nursery grounds. The lower estuary is a productive shellfish zone.

Due to Kepone contamination, fish harvesting is now restricted by the FDA Action Level determinations previously discussed. The river is open to the taking of oysters, clams, some migratory species, female crabs downstream from the James River Bridge, and several resident species, such as catfish. The river is closed to the taking of most freshwater sport species, except on a catch/release basis.

Because of the nature, size, and depth of the river, commercial navigation has been important on the James since colonial times. The complex river currents, augmented by tides, constantly shift and move sediments in the river. As a result, the U.S. Army Corps of Engineers maintains a deep water navigation channel from the Chesapeake Bay to Richmond.

The chemistry and biology of the James River varies from the mouth to Richmond. It is largely dependent on the magnitude of the freshwater discharge and the tidal action. Salinity concentrations change as a result of the salt wedge migration which is governed by the quantity of fresh water discharged to the estuary. The reach of the James River from Turkey Island near Hopewell to the Chesapeake Bay can be divided into four salinity zones. They are generally as follows:

Tidal Freshwater	River Mile 40 to 80	Salinity 0 to 0.5 ppth
Oligohaline	River Mile 25 to 40	Salinity 0.5 to 5 ppth
Mesohaline	River Mile 12 to 25	Salinity 5 to 15 ppth
Polyhaline	River Mile 0 to 12	Salinity greater than 15 ppth

IV. PROJECT APPROACH

ORGANIZING THE PROJECT

Development and management of the Kepone Mitigation Feasibility Project was assigned to EPA's Criteria and Standards Division, Office of Water and Hazardous Materials. Among the responsibilities of this Division is Section 115 of Public Law 92-500, "In-place Toxic Pollutants." However, since funding was not available under Section 115 appropriations, Phase I of the study was funded from other EPA resources. Resolution of resources and negotiations for support to conduct the project were initiated in November 1976. An allocation of $1.4 million for support was made. A comprehensive work plan was developed and negotiations were begun for support studies through interagency agreements with the U.S. Corps of Engineers (COE), the Department of Energy (DOE - at that time the Energy Research and Development Agency), and an allocation of funds to EPA's Gulf Breeze Environmental Research Laboratory and the Virginia Institute of Marine Science (VIMS). However, with detailed work plans and support agreements completed, the Agency was requested to delay action until the implications of the project could be evaluated in terms of the State of Virginia Kepone plan. Following this evaluation, the interagency agreements were consummated with the DOE and the COE on March 31, 1977.

At the same time the interagency agreements were signed, funds were transferred to the ongoing research programs of EPA's Gulf Breeze Laboratory and VIMS for specific tasks to be accomplished in time to support the requirements of the Kepone project. A year was allocated for project completion. The completion date was later extended to May 31, 1978 in order to permit more effective collaboration with the State of Virginia in review and preparation of the final project report.

Under the interagency agreement with the COE, Norfolk District, engineering studies to contain, stabilize, or remove Kepone-contaminated sediments were specified. Alternatives were to be evaluated with funding provided on a task basis to $400K. Arrangements were also made by the COE with the U.S. Fish and Wildlife Service (USFWS) of the Department of Interior for complementary ecological surveys of the Hopewell/James River area. Under the interagency agreement with DOE, the Battelle Pacific Northwest Laboratories were tasked with responsibility for: conducting sampling and analysis of the suspected sources of Kepone contamination in Hopewell and the James River; in coordination with VIMS, obtaining water quality, sediment, hydrologic and other data on the James River; modeling the transport and fate of sediments in the river; evaluating nonconventional Kepone mitigation techniques, which would complement those of the COE; and assessing the overall ecological impact of the current Kepone contamination and possible mitigation approaches. The funding for this effort was $800K with work proceeding under detailed task orders. The EPA Gulf Breeze Laboratory was assigned responsibility to provide scientific data and analysis on the effects of Kepone on the estuarine biota, including the biological accumulation, distribution and fate of Kepone. Of the $200K transferred to Gulf Breeze, $100K went to VIMS for associated field studies on the biota and hydrology of the James River. Exhibit IV-1 summarizes the individual project responsibilities.

To insure effective administration and coordination of the project, a management plan was developed concurrently. As shown in Exhibit IV-2, the project director was supported by an environmental scientist and an environmental engineer. Coordination channels were also established with the States of Virginia and Maryland, EPA's Region III, and other elements of the Environmental Protection Agency. Simultaneously, channels for information exchange were established with the State of New York's PCB Task Force which was faced with a similar river contamination problem.

EXHIBIT IV-1

KEPONE MITIGATION FEASIBILITY PROJECT RESPONSIBILITIES

DOE/BATTELLE

Sampling and analysis of suspected Kepone contamination to complement existing data.

Acquisition of water quality, sediment, hydrologic and other data in the James River in coordination with VIMS.

Modeling of transport and fate of Kepone in the James River.

Evaluation of nonconventional mitigation techniques.

Assessment of the overall impact of current Kepone contamination and possible mitigation approaches.

COE (With USFWS)

Analysis of worldwide sediment removal/dredging techniques and applicability.

Engineering studies to contain, stabilize, or remove Kepone-contaminated sediments.

Evaluation of environmental impact of selected engineering alternatives.

EPA GULF BREEZE LABORATORY

Effect of Kepone on estuarine biota, including biological accumulation, distribution and fate.

VIMS

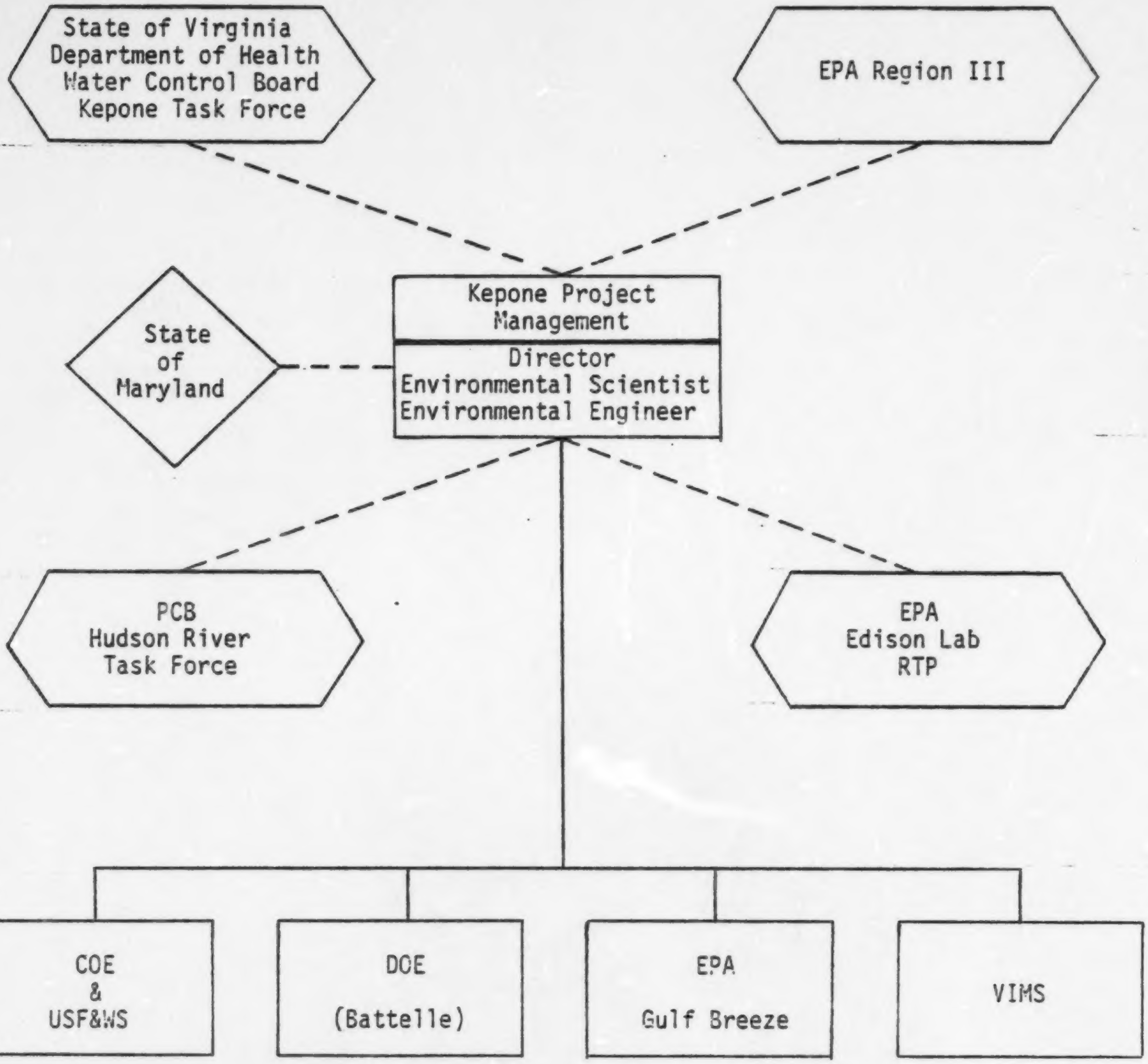
Field data on biota, sediments and hydrology of the James River.

EPA HEADQUARTERS

Program management and report.

Exhibit IV-2

KEPONE PROJECT MANAGEMENT AND ORGANIZATION


State of Virginia
Department of Health
Water Control Board
Kepone Task Force
EPA Region III
State of Maryland
Kepone Project Management
Director
Environmental Scientist
Environmental Engineer
PCB
Hudson River
Task Force
EPA
Edison Lab
RTP
COE & USF&WS
DOE (Battelle)
EPA Gulf Breeze
VIMS

LABORATORY STANDARDIZATION

Kepone is a very complex chlorinated hydrocarbon which can be detected by the use of electron capture-gas chromatography. When the Kepone incident occurred, techniques for measuring the chemical were rudimentary at best. Since many sample types were involved (i.e., sediments, plants, animals and water), and Kepone concentrations ranged between parts per million and parts per billion, chemists were confronted with a variety of problems which had to be solved to assure reliable analyses.

The first efforts on quality control and assurance were those of the State of Virginia Division of Consolidated Laboratory Services. In this program, samples of soil, fish, blood and water were sent to participating laboratories. The results of the analyses were statistically examined by the Consolidated Laboratories and returned to the participants. Following these efforts, fish and oyster samples were sent by the Food and Drug Administration in Washington, D.C. to their field laboratories and some laboratories within the State of Virginia. In addition, individual investigators exchanged samples with each other.

With the initiation of the Kepone Mitigation Feasibility Project, participants believed it necessary to institute a standardization procedure to assure the precision of Kepone results between the laboratories. Accordingly, the project arranged for the development and administration of a standardization procedure by the EPA Health Effects Research Laboratory at Research Triangle Park, North Carolina. Participating laboratories were:

U.S. EPA Gulf Breeze Environmental Research Laboratory
U.S. Fish and Wildlife Patuxent Wildlife Research Center
State of Virginia Division of Consolidated Laboratory Services
Virginia Institute of Marine Science
William H. Jennings Laboratory, Inc.
Battelle Pacific Northwest Laboratories

Four sediment sample groups were distributed and analyzed: (1) control without Kepone; (2) control known to have interfering compounds (PCB-Aroclor 1254); (3) James River Kepone-contaminated sediment sample; and (4) fortified (spiked) sample of known Kepone quantity. Participating laboratories were sent twelve blind 21-gram samples of the above groups, including replicates. In addition, an analytical standard was forwarded for the laboratories' use.

In general, the results of the laboratories appeared good - excellent in some cases - considering that several different analytical methods were employed in the various laboratories. The standardization procedure has been valuable for the laboratories in the Kepone Mitigation Feasibility Project because instruments have been thoroughly tested, analytical techniques have been perfected, and future Kepone results can be compared with greater confidence. Since the standardization, contractors and laboratories have examined initial project data and data generated prior to the project initiation. No significant adjustments were necessary in the use of previous data for the Kepone Mitigation Feasibility Project analyses. For water analyses of Kepone, laboratories have placed the limits of detectability with good reliability at approximately 0.02 parts per billion (ppb). A few laboratories feel confident about stating values lower than this. Sediment and animal tissue lower limits of detectability are usually placed at 0.02 parts per million (ppm).

PROJECT FIELD EFFORTS

Laboratory and field programs were undertaken as part of the EPA Kepone Mitigation Feasibility Study to provide the data needed to assess the possibility of eliminating the problem of Kepone contamination from the James River. These programs built upon the results of previous Kepone studies, as well as addressed new research areas required for a fuller understanding of the issue. The following sections discuss the details of the Kepone Mitigation Feasibility Project field efforts.

The field studies undertaken as part of the Feasibility Project were designed to satisfy the following needs:

1. Provide additional data on Kepone contamination in the James River;

2. Provide input data for modeling efforts of Kepone movement in the James River;
3. Provide an engineering and environmental data base for assessing alternative conventional mitigation measures in the Bailey Bay area;
4. Establish the distribution of Kepone residuals in Bailey Bay and its tributary streams;
5. Establish the distribution of Kepone residuals in the terrestrial areas of the Hopewell region; and
6. Identify potential sources of continuing Kepone contamination into the James River.

Data for Modeling

A plan was developed to undertake a joint field sampling program of the James River in June 1977. The sampling data were designed for use in developing, calibrating, and verifying computer simulations of Kepone movement in the James River as well as to provide data for the further assessment of Kepone contamination in the James.

Eleven sampling transects were designated. Eight of these transects were sampled by Battelle and four by VIMS. One transect was duplicated by Battelle and VIMS for comparison purposes. However, logistics and equipment acquisition problems prevented a simultaneous sampling cruise by Battelle and VIMS. The VIMS sampling was therefore accomplished in August 1977.

June Sampling Program

In June, Battelle Laboratories collected data at eight transects along a 70-mile reach of the James River from City Point at Hopewell to the James River Bridge. Three stations were located on each transect and one to three depths were sampled per station for each of three current conditions (flood, slack and ebb). The locations of these stations are listed below:

James River Bridge
Rocklanding Shoal
Hog Island
West Swann Point
Windmill Point
Jordan Point
Bailey Bay
City Point

The first four stations were located in the saline portion of the estuary, while the latter four stations were located in the freshwater portion. The Jordan Point, Bailey Bay and City Point stations were selected to provide better resolution in the Kepone source area. All cross-sections are tidally influenced.

The sampling data gathered in the field included: meteorological and hydrological information; channel and flow characteristics; physical and chemical characteristics of suspended load and bed sediments; and water quality characteristics. Kepone analyses were conducted on water, suspended load, and bottom sediment samples. Water quality parameters measured at each station and depth included water temperature, dissolved oxygen, pH, and conductivity.

August Sampling Program

In August 1977, personnel from VIMS performed their hydrographic survey at four James River transects which bracketed the turbidity maximum with three stations at each transect. The transects were located near the following: Herring Creek, West Swann Point, Brandon and Fort Eustis. Each survey was conducted for a period of approximately 100 hours to span eight tidal cycles. Parameters measured included total suspended sediment, salinity, dissolved oxygen, current direction and speed and tidal stage.

Mitigation Alternatives Data Base

Other field work involved compiling data required to assess the conventional Kepone mitigation alternatives developed by the Corps of Engineers for the Bailey Bay area. This included the collection of geotechnical, hydrological, and environmental information.

Under the supervision of the Norfolk District Corps of Engineers borings were taken in May 1977 in Bailey Bay and Bailey Creek to provide data on foundation potential for dams or dikes. Since the Kepone study was only in the concept stage of development, the subsurface investigation was limited to 12 borings with standard penetration testing. The locations of these borings, labeled DH-1 through 5, and 7 through 13 are shown on Exhibit IV-3.

Hydrologic field work was undertaken because no known detailed topographic data existed to facilitate the required preliminary design and associated cost estimates. Cross-sections were obtained on both Bailey Creek and Gravelly Run to aid the development of preliminary design features for each alternative, including flood routings and channel designs. The location of each cross-section is shown on Exhibit IV-4.

Under an agreement with the U.S. Corps of Engineers, the U.S. Fish and Wildlife Service performed an environmental assessment of Bailey

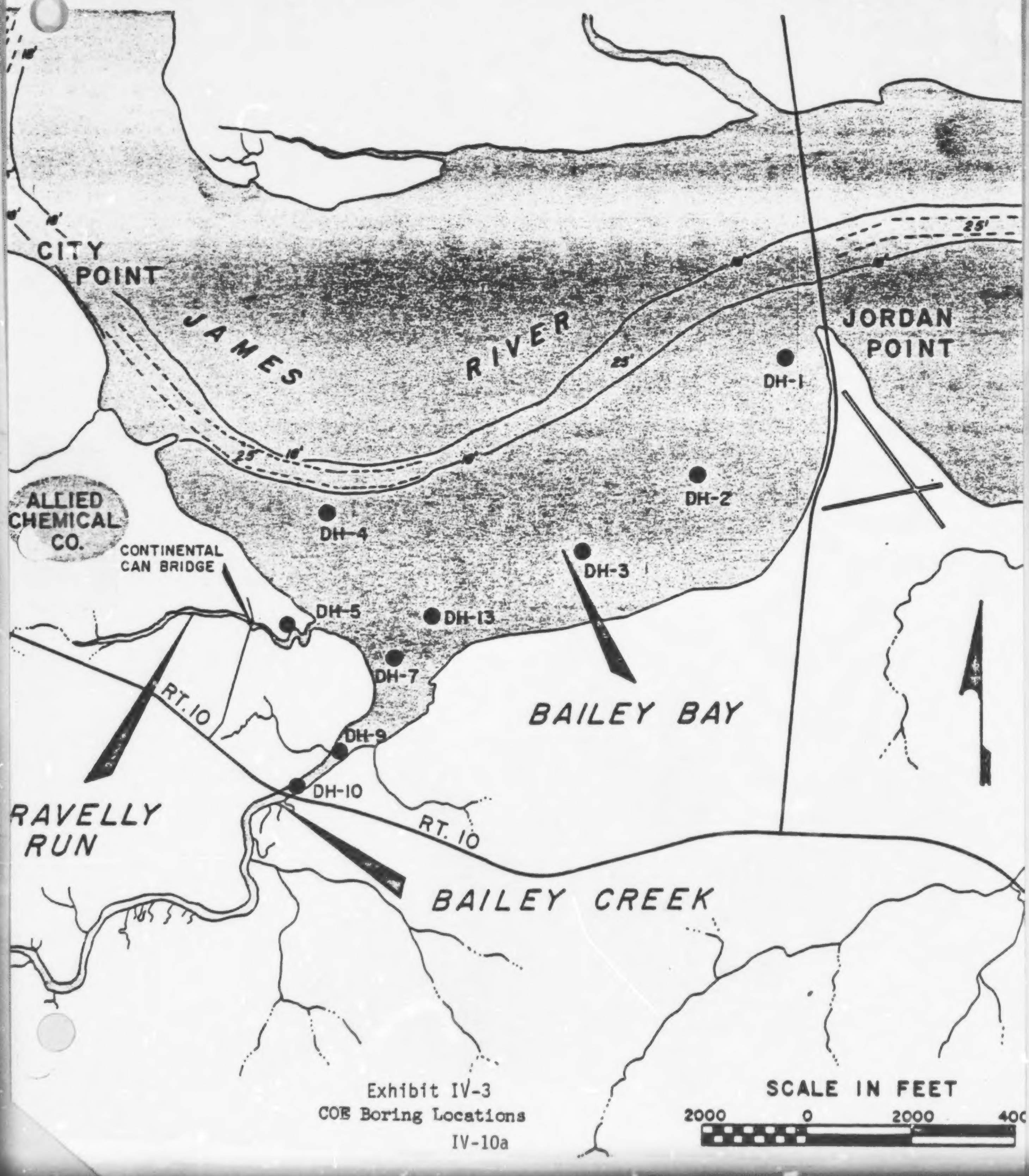

CITY POINT
JAMES RIVER
JORDAN POINT
25'
18'
25'
18'
25'
ALLIED CHEMICAL CO.
CONTINENTAL CAN BRIDGE
DH-1
DH-2
DH-3
DH-4
DH-5
DH-13
DH-7
DH-9
DH-10
RT. 10
RT. 10
BAILEY BAY
RAVELLY RUN
BAILEY CREEK
SCALE IN FEET
2000
0
2000
40

Exhibit IV-3
COE Boring Locations

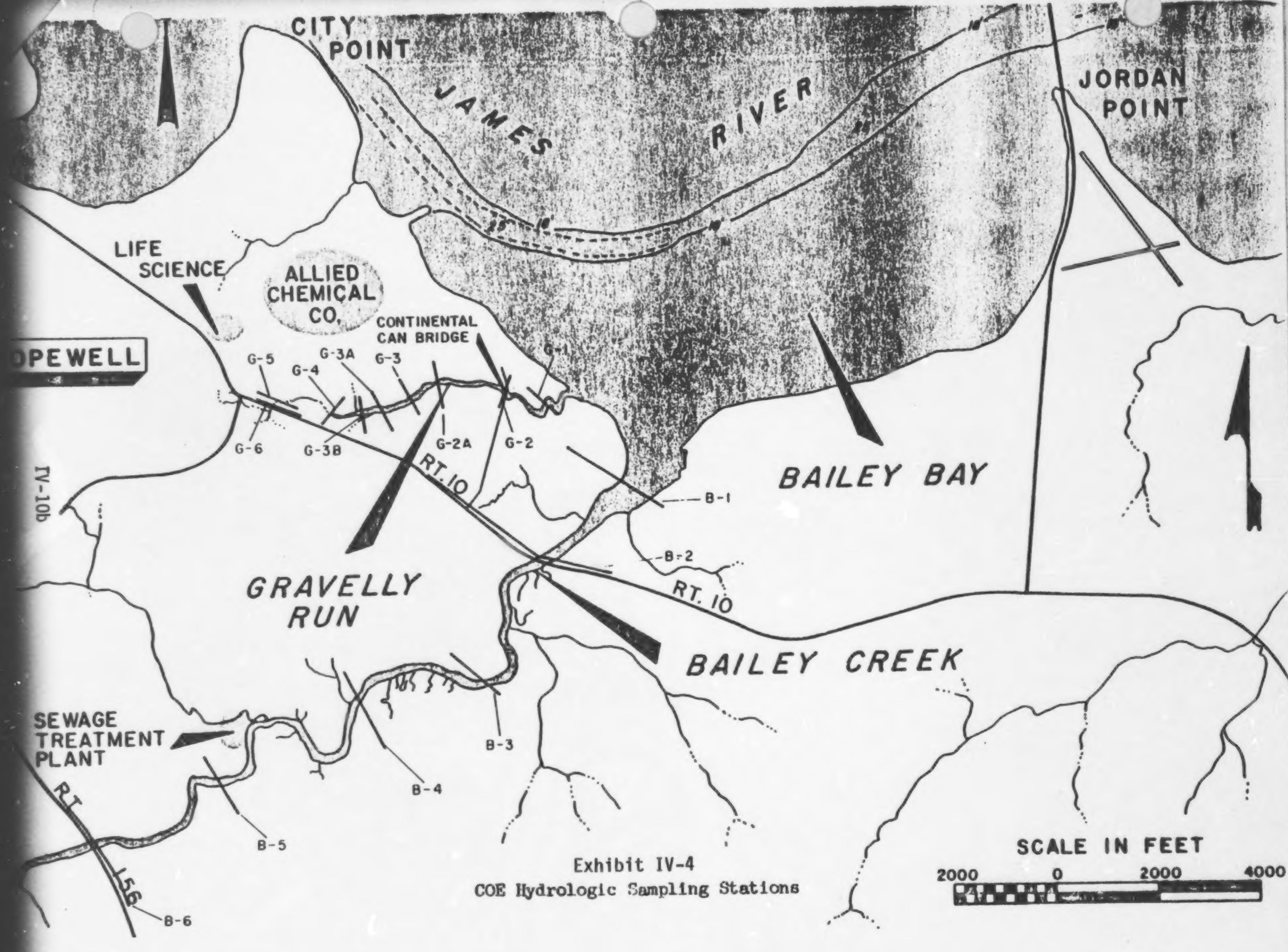

CITY POINT
JAMES RIVER
JORDAN POINT
LIFE SCIENCE
ALLIED CHEMICAL CO.
CONTINENTAL CAN BRIDGE
OPEWELL
G-1
G-2
G-2A
G-3
G-3A
G-3B
G-4
G-5
G-6
RT. 10
RT. 10
BAILEY BAY
B-1
B-2
GRAVELLY RUN
BAILEY CREEK
B-3
B-4
B-5
B-6
SEWAGE TREATMENT PLANT
RT. 156
SCALE IN FEET
2000
0
2000
4000

Exhibit IV-4
COE Hydrologic Sampling Stations

Creek and its associated wetlands in August 1977. Involved in this procedure was an environmental description of the sector and a habitat evaluation. This was accomplished through the use of an environmental inventory of the specified areas and with preparation of a general habitat map. Biologists made observations of wildlife through signs or actual sightings. The Corps did some limited water quality work and sediment analyses in preparation of the environmental assessment.

Fish and Wildlife Service biologists conducted their investigations of the wetland creeks to determine which wildlife species or groups of species appeared to be absent from the ecosystem and which would be expected in Bailey Creek if the Creek were not so heavily polluted. For comparison, similar field studies were undertaken in Powell Creek, the closest creek system along the James River with physiographic features similar to Bailey Creek. An attempt was made to identify pollutant pathways through the Bailey Creek ecosystem. Preliminary impact evaluations of the various structural alternatives being designed by the Corps were determined by the Fish and Wildlife Service.

Bailey Bay Kepone Distribution Determination

The thrust of the Battelle field sampling program in Bailey Bay was the collection of sediment cores for Kepone analysis. To establish sampling sites in the bay, a grid network was overlain to yield squares of 305 meters (1,000 feet) on a side. Every other square in a checkerboard was designated for core sampling. The sampling points were illustrated in Exhibit IV-5. Twenty-seven sites were identified for sampling in Bailey Bay. This is 37.5 percent greater than the minimum number necessary to evaluate contaminated sediments according to the EPA formula for aquatic sediments (EPA, 1974). Seven of these cores were divided into 2.5 cm (1 in.) thick slices to yield Kepone variations with depth. Four sampling locations were designated for heavy metals and broad spectrum gas chromatograph/mass spectrograph organic analysis. These samples served to indicate the presence of other contaminants which could potentially interfere with Kepone cleanup.

Identifying Kepone Distribution and Transport in Hopewell

A comprehensive sampling plan for Bailey Creek, Gravelly Run, the terrestrial areas of the town of Hopewell, the primary sewage treatment plant area, and the municipal landfill was established to quantify inflows of Kepone to Bailey Bay and the James River system.

Sediment

Since it was believed that significant amounts of Kepone were associated with the sediments of creeks flowing into Bailey Bay, sediment cores at 2,000 foot intervals beginning at the creek mouth

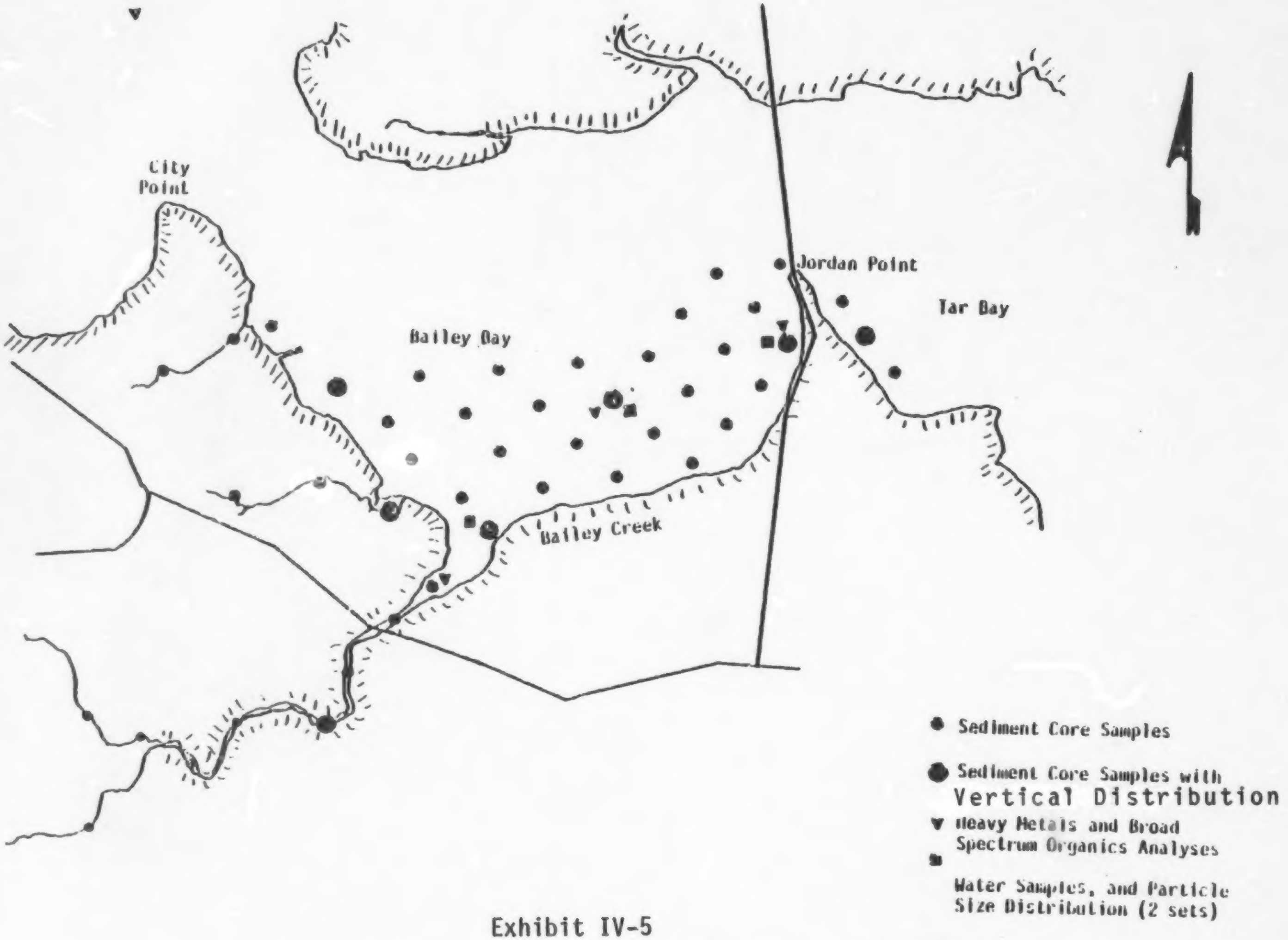

City Point
Bailey Bay
Jordan Point
Tar Bay
Bailey Creek
● Sediment Core Samples
● Sediment Core Samples with Vertical Distribution
▼ Heavy Metals and Broad Spectrum Organics Analyses
■ Water Samples, and Particle Size Distribution (2 sets)

Exhibit IV-5
Sampling Pattern for Bailey Bay and Tributaries

were taken on Bailey Creek, Cattail Creek, Gravelly Run, and Poythress Run. The upstream limit of sampling was State Highway 156 for Bailey Creek, a point 1,000 feet above any possible influence of the landfill; for Cattail Creek, the State Highway 10 bridge; for Gravelly Run and for Poythress Run, Station Street. Sediment samples taken in the Creeks were a composite of three stations on a bank-to-bank cross section.

Soil

Soil samples were taken at several locations in the Hopewell area to determine the extent of Kepone contamination in the soils of the area's watersheds. The sampling points were so located to ascertain the distribution and magnitude of soil Kepone levels, thereby giving insight into the possible significance of contamination of the James River from terrestrial sources. Particular attention was given to the area around the former Life Science Products plant. Other points were dispersed throughout the City of Hopewell and the area immediately surrounding the City, as illustrated in Exhibit IV-6. Site descriptions are given in Exhibit IV-7.

Water samples were taken to measure inputs of Kepone from streamflow, runoff, ground water, and seeps. Streamflow samples were collected from several locations on Bailey Creek, Cattail Creek,

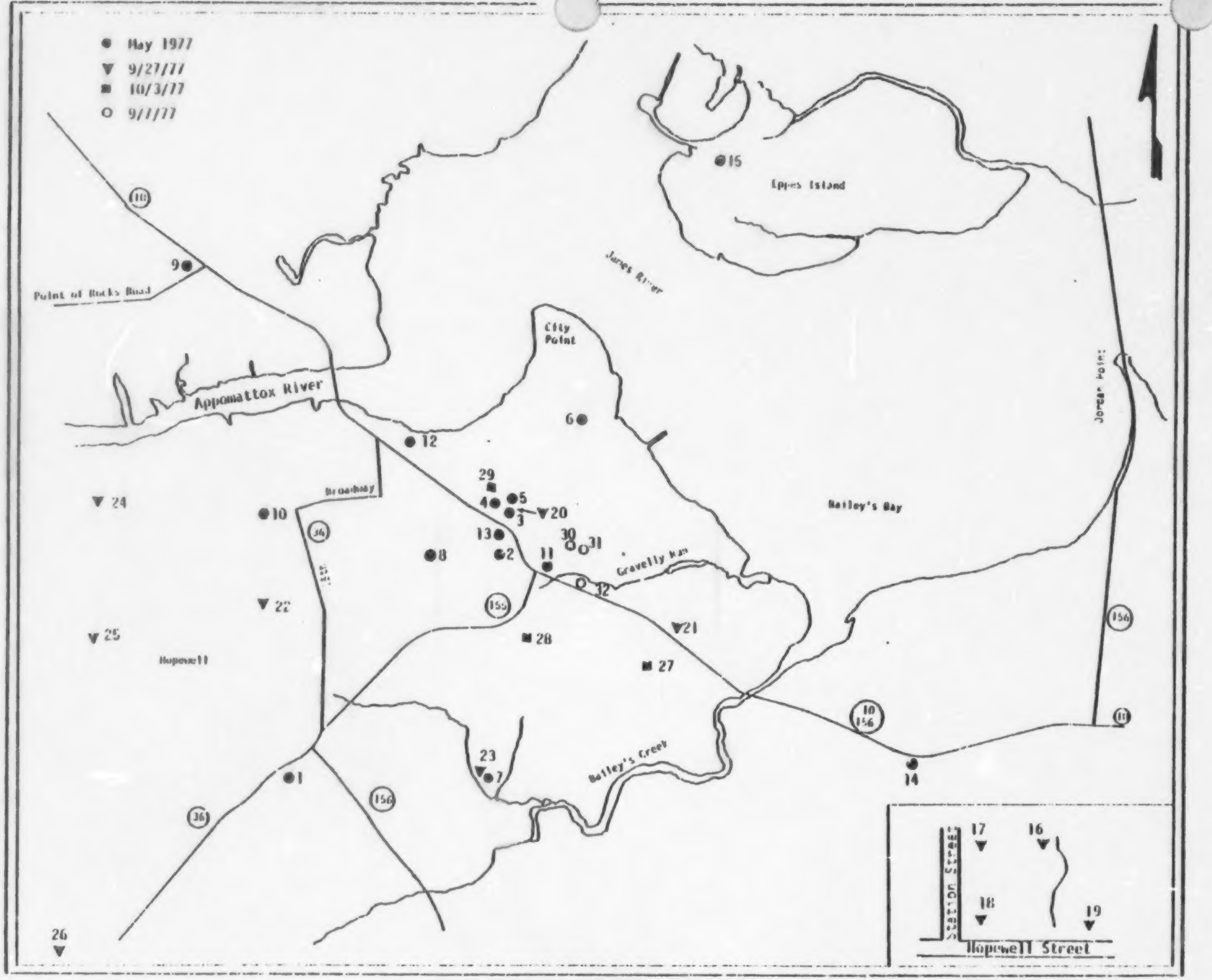

● May 1977
▼ 9/27/77
■ 10/3/77
○ 9/7/77
Epps Island
James River
Jordan Point
Bailey's Bay
City Point
Appomattox River
Point of Rocks Road
Broadway
Gravelly Run
Bailey's Creek
Hopewell
Station Street
Hopewell Street
10
36
156
155
10/156
1
2
3
4
5
6
7
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Exhibit IV-6
Sites for Soil Samples in Hopewell

EXHIBIT IV-7. SITE DESCRIPTIONS FOR SOILS SAMPLES

1. Church, north corner of Boston and Sunnyside Streets.
2. Baseball field behind James School.
3. North side Cavalier Ice Plant.
4. Nitrogen Park between State Well and Hopewell Streets.
5. Off northeast corner of Life Science Plant Building.
6. Park, corner of Burnside and Allen.
7. Near main Pump Station.
8. Grove of trees on LaPrade Street across from Industrial Piping and Supply.
9. Southwest corner of State Highway 10 and Point of Rocks Road.
10. Apartments, southwest corner of 20th and Broadway.
11. North side of State Highway 10 at Civic Clubs sign.
12. Apartment, corner of 2nd and Eppes.
13. Park, 100' east of the Hopewell News Building.
14. South side of State Highway 10 at FOP Lodge Road.
15. Just off road between Shirley Plantation and Eppes Island.
16. Nitrogen Park.
17. Nitrogen Park.
18. Nitrogen Park.
19. Nitrogen Park.
20. Life Science Products site next to the railroad track.
21. 20 feet north of Highway 10 across from the PAN site.

22. DuPont School playground

23. Main Pump Station.

24. Appomattox No. 2 Pump Station.

25. Sussex Drive Pump Station.

26. Western Street Pump Station.

27. Pebble Ammonium Nitrate site.

28. Black field where liquid waste from tankers was disposed of.

29. Northwest corner of the Life Science Products site.

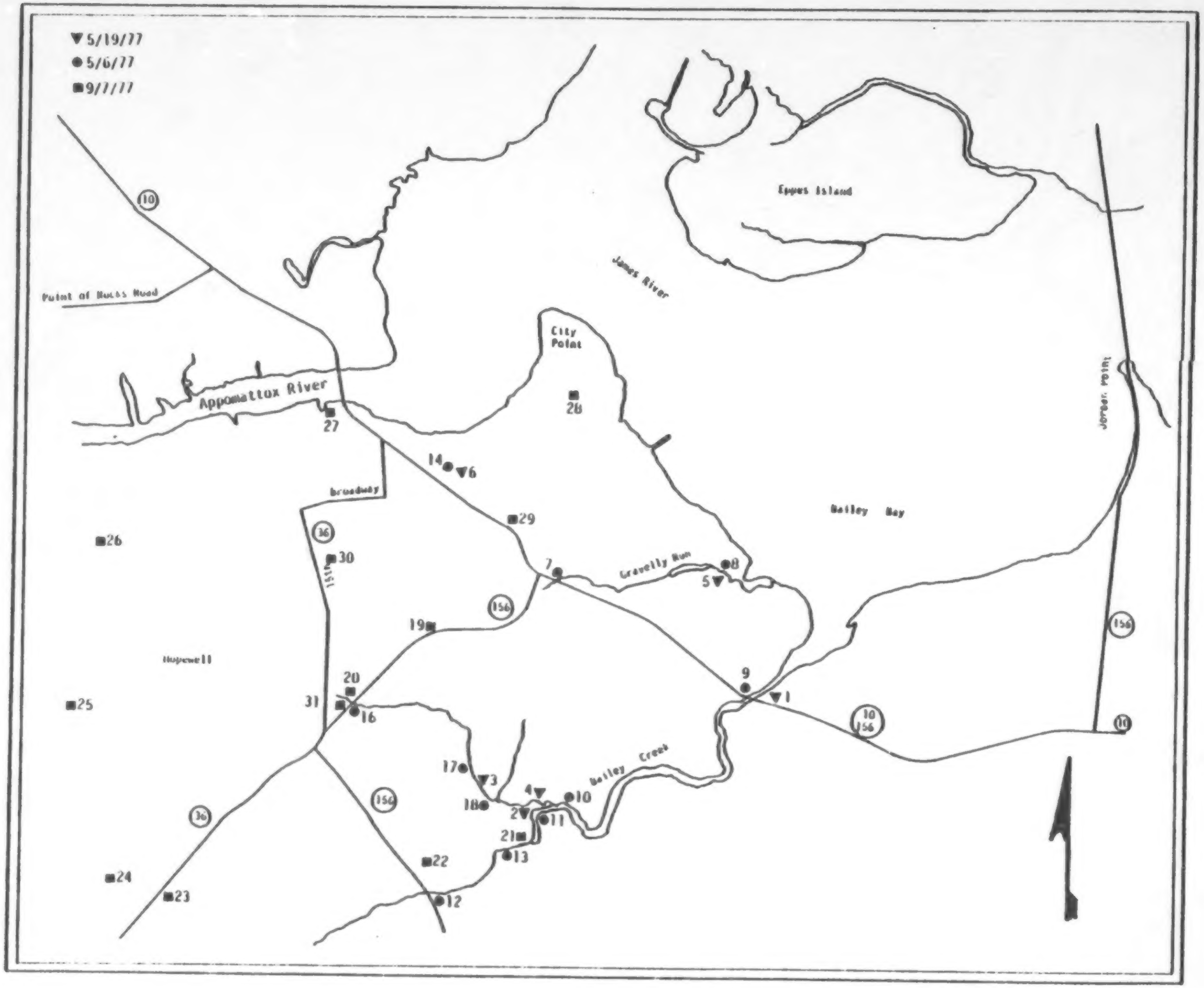
30. North side of Allied Chemical's Semi-Works plant.

31. West side of Semi-Works plant.

32. Between Gravelly Run and State Highway 10 across from the first Allied effluent discharge.

Gravelly Run, Moody's Creek, Poythress Run, and Cabin Creek. When possible, each station was sampled on two days: one during low flow; one during a period of high runoff.

Samples of storm runoff were also taken from areas suspected to contain high Kepone concentrations (Life Science Products plant area, landfill area), as well as from representative points throughout the city. Sample sites are displayed in Exhibit IV-8 and described in Exhibit IV-9. Ground water samples for Kepone analysis were taken from seven test wells bored by the State Water Control Board and two private wells in the area. Water was also sampled in the vicinity of the Kepone/sludge lagoon. Samples were collected from within the lagoon, in a puddle outside the dike, and from ground water seeps flowing into Bailey Creek immediately below the lagoon.


▼5/19/77
●5/6/77
■9/7/77
Eppes Island
James River
City Point
Bailey Bay
Jordan Point
Appomattox River
Point of Rocks Road
Broadway
15th
Gravelly Run
Bailey Creek
Hopewell
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36
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156
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Exhibit IV-8
Surface Water and Runoff Sample Locations

EXHIBIT IV-9. SITE DESCRIPTION FOR RUNOFF AND CREEK WATER SAMPLES

1. Bailey Creek at State Highway 156.
2. Bailey Creek just above Cattail Creek.
3. Cattail Creek at power line above Landfill.
4. Cattail Creek just above Bailey Creek.
5. Gravelly Run at Continental Can Road.
6. Drainage ditch at Station Street east of crossing.
7. Gravelly Run at State Highway 10.
8. Gravelly Run at Continental Can Road.
9. Bailey Creek at State Highway 10.
10. Bailey Creek below confluence with Cattail Creek.
11. Bailey Creek above confluence with Cattail Creek.
12. Bailey Creek at State Highway 156.
13. Bailey Creek at power line above Hopewell Treatment Plant.
14. Drainage ditch at Station Street easternmost crossing.
15. Cattail Creek at State Highway 156.
16. Cattail Creek at power lines.
17. Cattail Creek at sewer line crossing.
18. Corner of LaPrade and Highway 156.
19. Corner of Arlington and Highway 156.
20. Bailey Creek upstream of Hopewell Treatment Plant effluent and the seeps below the Kepone/sludge lagoon.
21. Corner of Locust and Dellrose.

22. Dinwiddle Avenue 100 feet southeast of corner of Oaklawn.

23. Corner of Smithfield and Cedar Level.

24. Cabin Creek under Jackson Farm Road.

25. End of West Broadway near the railroad tracks.

26. Riverside Avenue across from the Hopewell Yacht Club.

27. Corner of Brown and Burnside.

28. Life Science Products plant site.

29. Corner of 14th and City Point.

30. Same location as Sample 20.

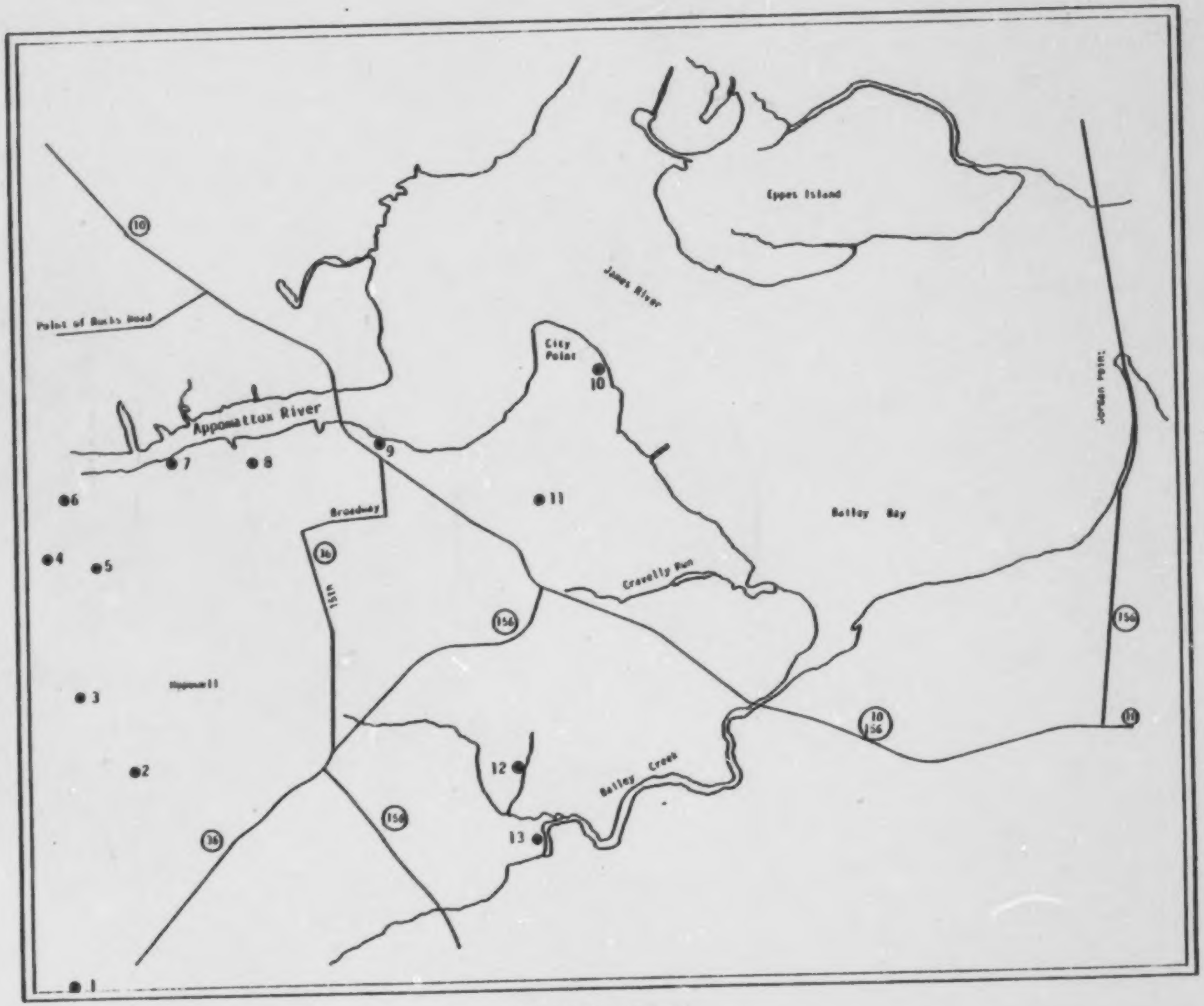
Sewer System

Initial sampling in the Hopewell sewer system focused on the sewage treatment plant and on the sewer line connecting it with the Life Science Products site. This included the Station Street and main pump stations through which the effluent and runoff from the Life Science Products plant site were pumped. Samples were taken of the water, slimes, and sludges in these facilities. In addition, raw sewage and slime samples were taken from 11 pump stations in the Hopewell municipal sewage system through which Life Science Products effluent and runoff has not flowed. The pump stations of the sewer system are located and described in Exhibits IV-10 and IV-11.

Follow-up Sampling

Following analysis of samples collected in the initial field study plan, it became apparent that additional sampling would be beneficial. Certain significant findings warranted follow-up field sampling in order to establish the magnitude of potential Kepone problems. Additional field work was undertaken at the Pebbled Ammonium Nitrate (PAN) plant site and the southeast corner of the Hopewell sanitary landfill.

At the PAN site, 14 shallow holes were drilled with a hand auger. Samples were collected from the surface and at a depth of five feet.


10
Point of Rocks Road
Appomattox River
James River
Eppes Island
City Point
Jordan Point
Bailey Bay
Gravelly Run
Bailey Creek
Broadway
36
15th
156
10
156
Hopewell
1
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10
11
12
13

Exhibit IV-10
Pump Station Solids and Wastewater Sample Locations

EXHIBIT IV-11. PUMP STATIONS LOCATED IN EXHIBIT IV-10.

1. Western Street
2. Sherwood Land
3. Sussex Drive
4. Cabin Creek
5. Appomattox No. 1
6. Appomattox No. 2
7. Park Avenue
8. Mansion Hills
9. Sixth Avenue
10. Water Street
11. Station Street
12. Main
13. Bailey Creek

Next, 8 deep holes were bored to depths between 35 and 50 feet, and samples taken at 1 to 5-foot intervals. Several sediment cores were also collected in the marshy areas around the PAN site. Four sediment cores were taken from the site itself, and 9 cores collected from the Moody's Creek marsh immediately down-flow. A series of runoff samples and several subsurface soil samples using a 10-foot hand auger were also taken.

Several series of samples were collected adjacent to the southeastern edge of the Hopewell landfill in order to establish the magnitude and transport of highly concentrated Kepone residuals detected in this area during previous sampling. Field work included collection of several 1 to 2-foot cores and 4-inch grabs of sediment to calculate the amount of Kepone residing in this area. Runoff and hand-augered soil samples to depths of 10 feet were gathered to detect any possible transport pattern.

PROJECT LABORATORY EFFORTS

Numerous laboratory studies were conducted to support the Kepone Mitigation Feasibility Project, including physical, chemical, biological, toxicological and engineering. The following describes those efforts by the several contractors or laboratories.

EPA Gulf Breeze Environmental Research Laboratory

Studies of Kepone Availability from Water

1. Toxicity and uptake of Kepone in four species of marine unicellular algae.

   Output: EC 50 values and Kepone concentrations values

2. Acute toxicity of Kepone to estuarine animals.

   Output: Acute 96-hour LC50 values and average bioconcentration factors for:

Grass Shrimp	*Palaemonetes pugio*
Blue Crab	*Callinectes sapidus*
Sheepshead Minnow	*Cyprinodon variegatus*
Spot	*Leiostomus xanthurus*
Mysid Shrimp	*Mysidopsis bahia*
Oyster	*Crassostrea virginica*

3. Full life cycle bioassay studies.

Sheepshead Minnow	*Cyprinodon variegatus*
Mysid Shrimp	*Mysidopsis bahia*

4. Bioaccumulation and loss of Kepone in estuarine animals (multiple concentrations).

Oyster	*Crassostrea virginica*
Sheepshead Minnow	*Cyprinodon variegatus*
Spot	*Leiostomus xanthurus*

Grass Shrimp	*Palaemonetes pugio*
Blue Crab	*Callinectes sapidus*

5. Studies on Kepone accumulation from contaminated food. Studies on the bioaccumulation and toxic effects of animals exposed to Kepone contained in their food, in Kepone-contaminated water, and in Kepone-uncontaminated water.

   Algae-Oyster food chain
   Brine Shrimp - Mysids - Spot food chain

6. Studies on sensitive life stages

Juvenile Blue Crab	*Callinectes sapidus*
Larval Oysters	*Crassostrea virginica*
Sheepshead Minnow	*Cyprinodon variegatus*

7. Studies of bioaccumulation in, and toxicity to estuarine animals in contaminated sediments.

8. Studies on biodegradation, volatility, and sorption-desorption.

The above laboratory studies were made to determine the toxicity of Kepone to representative animals. Both acute and chronic studies were performed on these animals for which there are accepted culture methods and comparative data for other toxic materials. Many species tested are indigenous to the James River and Chesapeake Bay ecosystem and are economically significant to the seafood industry. They constitute important links in the estuarine food chains. Laboratory Kepone exposure levels were related to field observations on the James River where possible. This research was directed toward the development of Kepone indices for water, sediment and food.

The Virginia Institute of Marine Science (VIMS) has also undertaken a variety of studies relating to Kepone in the aquatic environment. Efforts with Kepone have concentrated on improving the accuracy of Kepone detection, partition coefficient determinations, and instrumentation development. Biologists at VIMS studied the Kepone effects on James River organisms in the laboratory, such as clams and oysters. These shellfish were examined over time as they were exposed to Kepone-contaminated sediments, either in suspension or by association with sediments. Such efforts are continuing under new funding from the State of Virginia as a result of a recent partial settlement on Kepone claims between the State and Allied Chemical.

The U.S. Army Corps of Engineers, in developing their eighteen conventional alternatives in Bailey Creek, Bailey Bay, and Gravelly Run, used data from a previous grain size study at Windmill Point to perform their engineering studies. The data were used to evaluate the foundation, stability and settlement potential at or near the mouth of Bailey Creek. The data also were used to determine the availability and type of borrow material available and subsequent shear strengths.

Battelle Pacific Northwest Laboratories performed numerous experiments while investigating nonconventional mitigation techniques. Fixation and stabilization processes were evaluated on the basis of: (1) short-term elutriate tests; and (2) long-term leach tests. Physical/chemical, elutriate/slurry treatment processes were also investigated. Battelle Columbus Laboratories performed degradation experiments with radio-labeled Kepone.

Several aspects of photolysis were examined. "Landfarm" vessel experiments were used to investigate photochemical degradation. The effects of amine solutions and sunlight exposure were tested for their efficiency in degrading Kepone as well as experiments using chlorine dioxide (Oxine) to oxidize Kepone with and without sunlight. Ozonation was tested because of its oxidizing capability.

Kepone contaminated sediments were exposed to x-ray radiation by Battelle Laboratories to determine if Kepone degradation could be achieved by oxidation of Kepone dissolved in water. Also investigated were *in situ* Kepone amelioration techniques, including the use of sorbents, such as activated carbon, coal, and some synthetic adsorbents produced by Diamond Shamrock, Rohm and Haas, Bently Laboratories, and Calgon. Polymer films were investigated because they might be able to provide a means of retarding or limiting the availability of Kepone to the surrounding environment. In the selection of a sealing bottom film tear strength, tensile strength, water resistance, chemical resistance, temperature resistance, and handling characteristics were considered.

Battelle performed experiments with barley plants to determine if plants could take up Kepone through their roots to edible parts. There had been concerns that Kepone around the Hopewell area could be taken into food crops or plants fed to livestock, so barley experiments were deemed appropriate.

PROJECT-RELATED FIELD EFFORTS

Integration of Previous Kepone Studies

In designing an approach to the Kepone Mitigation Feasibility Study, an effort was made to integrate the study with previous Kepone research programs. Following closure of the Life Science Products plant in Sept. 1975, several programs were undertaken to establish the magnitude of the Kepone problem. These included collecting human and environmental samples for Kepone analysis, and laboratory studies designed to understand the characteristics of the chemical. Results from a number of these studies were incorporated in the Kepone Mitigation Feasibility Project to provide insight into the problem. These studies are discussed briefly below.

The Virginia Water Control Board collected a variety of samples from the Hopewell area and the James River beginning in 1975. These included sediment, aquatic biota, soil, ground water, and runoff samples which were analyzed for Kepone content. Of particular value to the Feasibility Project were the results of the sediment sampling which established the general pattern of Kepone residuals in the James River. Virginia Water Control Board sediment sampling is a continuing program in which cores from more than 50 stations are collected throughout the James River system annually.

Sediment cores analyzed in previous research efforts by the Virginia Institute of Marine Science also provided useful data on Kepone distribution in the James River. Their sampling program involved systematically collecting core samples during each of the four seasons beginning in September 1976.

Data used from previous sampling were provided by the City of Hopewell. Samples of sewage sludge and effluent have been collected by the city on a regular basis and analyzed for Kepone. In 1976 these were sampled weekly, then beginning in April 1977, the sampling period was changed to a monthly basis.

KEPONE-RELATED INVESTIGATIONS

In addition to the contractors and laboratories funded through the Kepone Mitigation Feasibility Project, the following groups had been or are continuing to study Kepone and its effects. The information and laboratory data generated by these groups has been incorporated by the Feasibility Project.

Allied Chemical has had its own research program examining ways in which Kepone could be removed from the James River or ways in which Kepone effects could by attenuated. Allied Chemical also has various contractors, such as EG&G, Bionomics, Inc. who are examining some of the biological implications of Kepone. Allied Chemical's laboratory research efforts are continuing.

U.S. Sport Fisheries and Wildlife Columbia, Missouri Pesticide Laboratory is conducting research on Kepone and Mirex uptake, storage and elimination in aquatic food chains. Also being studied is the microfaunal metabolism, including aerobic and anaerobic conditions. Physiological profiles are being derived and indications obtained to determine how perturbations can interfere with geochemical cycles.

Dr. Rita Colwell at the University of Maryland has been investigating possibilities of Kepone degradation by microorganisms (Orndorff, et al., In Press).

Design Partnership Consulting Engineers (Flood and Associates, Inc.) had conducted several laboratory studies for the State of Virginia in 1976, including the possibility of anaerobic biodegradation of Kepone. A report of all of their findings is currently under review by the State of Virginia.

The EPA Office of Research and Development has funded a study, conducted by the National Research Council, on Kepone, Mirex and Hexachlorocyclopentadiene. The report is now in draft form, but should be publicly released later this year.

The National Cancer Institute (NCI, 1976) conducted a study on the potential carcinogenicity of Kepone. Their report covered a year and a half of laboratory studies in mice and rats. A new joint study is being developed between NCI and the National Institute of Environmental Health (NIEH) to examine the human carcinogenicity risk associated with Kepone.

Envirogenics has recently been studying a process to destroy chlorinated hydrocarbons through the use of catalysts which facilitate the reduction of chlorine functional groups to form chlorides in solution. Their experiments have utilized a copper-iron catalyst in a reductive column with sand as the working substrate. Westgate Research Corporation has experimented with the combined use of ozone and ultraviolet irradiation in the degradation of Kepone. Details on of the above studies are included in Appendix A.

MODELING EFFORTS FOR KEPONE TRACKING

The assessment of Kepone distribution and its migration pattern must take into account the Kepone/sediment/river water interactions. Because of the lack of existing verified generalized mathematical models, engineers have had to rely on field studies or experience to estimate the distribution of contaminant concentrations. Field studies are useful to evaluate the present Kepone distributions in the James River, but such measurements cannot be used to predict accurately the future Kepone inventory and its dispersion unless hydrological and other conditions remain similar in the future to those which prevail during the monitoring periods. To deal with such eventualities, mathematical simulation must be undertaken.

Several model concepts were proposed for use in the Kepone project. However, the only comprehensive model sufficiently developed to be utilized in the time frame of the project was Battelle's model of the FETRA and SERATRA codes by Onishi at Battelle (Onishi, et al., 1976, 1977a, 1977b, 1977c. The appropriateness of the model was confirmed by a recent workshop on the evaluation of mathematical models (Oak Ridge National Laboratory, 1978). The workshop indicated that there are only two computer models, the FETRA and SERATRA codes, presently available to calculate migration of contaminants by taking into account the interaction between the contaminants and sediment (e.g. contaminant adsorption by sediment, desorbtion from sediment, deposition and resuspension of contaminated sediment). Both models are time-dependent, two-dimensional transport models that calculate migration of sediment and dissolved and particulate pollutants. FETRA solves longitudinal and lateral distributions of sediments and contaminants, while SERATRA predicts longitudinal and vertical concentrations. Because of the importance of lateral distributions of Kepone in the tidal James River, the FETRA code was selected for this study.

The Kepone Mitigation Feasibility Project Model

The Battelle mathematical model was adapted to simulate sediment and Kepone transport and their interactions in the tidal James River. This model simulates transport of Kepone by taking account of Kepone/sediment/river water interactions. The original model was developed for sediment and radionuclide transport prediction in the Columbia River. The expanded model applied to the James River has been verified both through comparisons of analytic and model predictions and by comparison with field data from the James. This verification, as well as model results, are discussed in Chapter VII. The detailed description of the model is contained in Appendix A of this report.

The mathematical simulation of Kepone migration in the tidal James River consisted of three submodels: (1) sediment transport model; (2) dissolved contaminant transport model; and (3) particulate contaminant transport model. The FETRA code, consisting of these three submodels, then computes sediment and contaminant simulation for any given time. Sediment transport has been modeled for three sediment types (i.e., cohesive sediments, noncohesive sediments, and organic matter). The simulation of Kepone transport considers dissolved and particulate Kepone (attached to sediments). Particulate Kepone has been analyzed separately for that adsorbed by sediment in each sediment type. The model covers the tidal portion of the James River to Burwell Bay.

The output of the model assists in answering two key questions related to Kepone contamination of the James River.

1. How much time will be required for the River to "cleanse" itself through natural dispersion?

2. What volumes and concentrations of Kepone can be expected to pass Burwell Bay and enter the Chesapeake Bay?

Other Modeling Efforts

A related modeling effort under development is that of Dr. Donald O'Connor of Manhattan College, whose work has been supported by EPA's Gulf Breeze Laboratory. However, this model has not been developed for operational application to the James River problem at this time. The model under development is an extension of a water quality model for estuaries. The model design incorporates physio-chemical mechanisms such as hydrodynamic transport, adsorption to and desorption from the suspended and bed solids, and settling and resuspension of these solids. The model will also address bio-ecological phenomena such as assimilation and excretion routes through the various components of the food chain.

The Virginia Institute of Marine Science is also developing mathematical models to simulate transport of Kepone in the tidal portion of the James River. One model simulates sediment transport, including Kepone dissolved in water and Kepone adsorbed to sediment particles. The model will include consideration of the turbidity maximum with expansion to account for Kepone pathways through living organisms. It will simulate the movement for a time period of days or weeks. A tidal-average model is being designed to simulate the Kepone movement for a time period of months or years.

V. KEPONE TRANSFER, TRANSPORT AND DISTRIBUTION

BEHAVIOR OF KEPONE IN SEDIMENTS, WATER COLUMNS, AND SPECIES

Kepone resides in the soil, sediments, water, and biota of the Hopewell area and the James River Basin. Much of this contamination has moved from where it was originally deposited. The translocation continues at the present time and is an important factor in determining the long-term implications of Kepone contamination. It is, therefore, important to examine the various pathways by which Kepone moved through the environment. The pathways include physical and biological mechanisms in the air and water as diagrammed in Exhibit V-1. Pathways examined for Kepone movement patterns included volatilization, sorption-desorption, plant uptake, bioconcentration, and physical movement of Kepone-laden suspended solids. These are discussed individually in the following sections. Kepone movement in the James River is the subject of the sediment transport modeling effort described in Chapter VII.

Volatilization

Laboratory studies revealed the lack of Kepone volatilization from both water and sediment/water systems (Appendix C, No. 12; Appendix A). The data suggest that volatilization is not a significant factor in the fate of Kepone in the James River. Continued persistence of Kepone in the James River supports these observations.

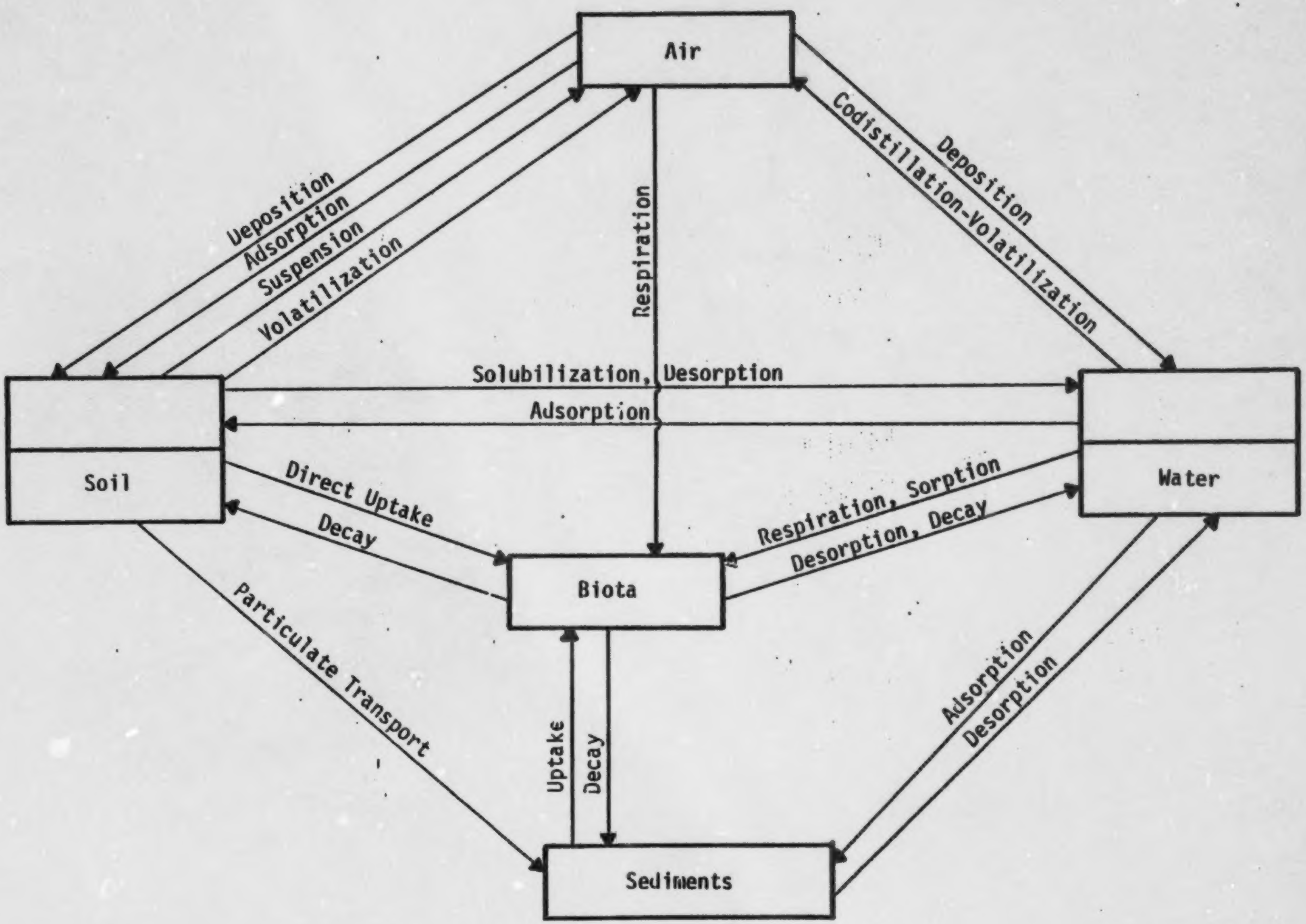

Air
Water
Soil
Biota
Sediments
Deposition
Adsorption
Suspension
Volatilization
Respiration
Deposition
Codistillation-Volatilization
Solubilization, Desorption
Adsorption
Direct Uptake
Decay
Respiration, Sorption
Desorption, Decay
Particulate Transport
Uptake
Decay
Adsorption
Desorption

Exhibit V-1 Kepone Pathways in the Environment

Sorption

Sorption dynamics predict that an equilibrium exists for Kepone between sediment and water (Kd = (ppb water)/(ppb sediment)). Field observations (Appendix C, No. 17; Appendix A) reflect higher concentrations of Kepone in sediments as compared to Kepone concentrations in water (at or below detection limits).

Partition coefficient (Kd) averages for water and sediment from the James River near Hopewell are about 1 to 5 x 10^{-4} (Appendix C, No. 17). These sediments contained high levels of organic carbon (13 to 20 percent). In the field, Kepone concentrations are highest in the larger-sized, high-organic particles (Appendix C, No. 17; Appendix A).

Laboratory studies (Appendix A; Appendix C, No. 12) with reference sediments and with James River sediment revealed Kd values ranging from 10^{-3} to 10^{-4}. Sediments with higher organic content displayed greater affinity for Kepone (marsh sediment; o.c. = 20 percent; Kd = 10^{-4}). These coefficients were unchanged for a given sediment in batch sorption tests when Kepone concentrations were varied 100-fold (Appendix C, No. 12). Kepone partitioning was not affected by salinity, temperature, aeration, or sunlight (Appendix C, No. 12 and No. 17; Appendix A). Although high pH ranges affect Kepone sorption between sediment and water, environmental pH ranges (6 to 8) do not influence the partition coefficient (Appendix C, No. 17; Appendix A).

Since the partition coefficient for Kepone is independent of concentration, temperature, aeration, and sunlight for a given sediment, a replacement of Kepone-contaminated water, with uncontaminated water will predictably cause Kepone to desorb from the sediment. Batch sorption experiments confirmed that Kepone was desorbed from James River sediment by water replacement. Continuous-flow sediment/water systems lost Kepone at constant rates and their partition coefficients were similar to the batch experiments (Appendix C, No. 12).

These considerations are important for predicting Kepone movement in the James River. Due to Kepone's preference for sediments with high organic content (Kd = 10^{-4}), Kepone movement in the river is dependent on sediment transport mechanisms. However, a dynamic exchange between Kepone-contaminated sediment/water and uncontaminated sediment/water influences Kepone transport predictions. Kepone in the water of the James River is below conventional detection levels, but it is still available for uptake by aquatic organisms.

Contaminated sediment provides a direct source of Kepone to some organisms and acts as a continuing reservoir of Kepone for dissolution into water. Accordingly, any major cleanup efforts will have to be directed toward the sediments, where the bulk of the Kepone resides.

Kepone Bioconcentration in Species

Although Kepone is intimately bound to sediments of the James River, it can desorb from those sediments, or organisms can extract it from the sediments to become incorporated into living systems. It can be passed between organisms readily as one organism uses another as food. Kepone is also available to animals from the water, but the exact mechanisms of exchange is not fully understood.

Walsh, et al. (Appendix C, No. 4) has shown that unicellular algae can readily bioconcentrate Kepone at many times the concentration which had existed in the surrounding water. For the four marine algae tested, Kepone bioconcentration factors ranged from 230 to 800 times the amount of Kepone found in the surrounding water. Thus algae, constituting an integral part of the James River food web, have the potential of concentrating Kepone on a primary level and then making it available to other species at higher levels.

Oysters, which filter the water for food, could consume contaminated algae and increase the amount of Kepone in the shellfish's body. Haven and Morales-Alamo (Appendix C, No. 18) have shown in lab experiments that oysters (Crassostrea virginica) can bioconcentrate Kepone from the surrounding water from quantities as low as 0.082 ug/l (ppb) to near (0.203 ug/g (ppm)) the FDA Action Level for shellfish of 0.3 ug/g (ppm). They also showed different routes of Kepone transport even in the same species. Kepone concentration usually ranged higher in the oyster feces (11,500 to 55,500 times), than in the "pseudofeces" (3,000 to 20,000 times). Pseudofeces are particles rejected by the shellfish as unfit to eat and which never enter the mouth. Bahner, et al. (Appendix C, No. 9) has shown in oysters a Kepone bioconcentration factor from water of approximately 9,300 times the amount of Kepone in the surrounding water.

Animals can gain Kepone by uptake from the water, from ingested sediments, and from eating contaminated organisms or their remains (Appendix C, No. 5, 18 and 14). The alosin fish group, such as alewife, shad and herring, filter the water to extract small particles of food. Through this process, Kepone could enter the fish, but it is not clear if dissolved Kepone is leaving the water as it passes over gill membranes, or if Kepone attached to suspended particulate material is consumed with the food particles.

For lugworms (Arenicola cristata) and probably for other benthic invertebrates, Kepone can accumulate through feeding contact with contaminated water. Kepone was acutely toxic to lugworms during a 144 hour experiment at a concentration of 29.5 ug/l (ppb) (Appendix C, No. 13). In addition, James River sediments with 0.25 ug/g Kepone were toxic to lugworms and fiddler crabs (Uca pugilator). These animals ingested the sediments and accumulated high burdens of Kepone.

No lugworms survived more than 21 days of exposure to the sediments, while fiddler crabs did not appear to be affected by exposure to Kepone, but depuration was slow (Bahner, et al. in preparation).

Bluefish, carnivores at the top of the food web in the James River ecosystem, eat large quantities of other fish, such as alewives, menhaden, etc. When bluefish enter the James River in the spring, as part of their annual northward migration, they generally have nondetectable to low amounts of Kepone. After several weeks in the river, they may approximate or exceed the FDA Action Level of 0.3 parts per million for fish (Bender, et al. 1977).

Blue crabs (Callinectes sapidus) from the James River averaged 0.19 ug/g Kepone for females and 0.81 ug/g for males. The males spend a greater proportion of their lives in the river system than do females and this habit probably accounts for the observed difference in Kepone body residues (Bender, et al. 1977a).

Kepone was administered to blue crabs (Callinectes sapidus) in seawater (0.03 or 0.3 ug/l) or food (oysters at 0.25 ug/g). The crabs were found to take up Kepone in the 56 day experiment primarily through contaminated food (oysters). When the crabs were held for 28 days in Kepone-free water and with Kepone-free oysters, no loss of Kepone was evident. In a second phase of the experiment conducted over a 90-day period, blue crabs were fed oysters (0.15 ug/g Kepone) from the James River and laboratory-contaminated oysters (0.15 or 1.9 ug/g Kepone). Blue crabs fed Kepone-contaminated oysters followed by a diet of Kepone-free oysters for 90 days had detectable concentrations of Kepone in their tissues. Crabs, which ate oysters containing Kepone in concentrations similar to those found in James River oysters, died or molted less frequently than blue crabs fed Kepone-free oyster meats (Appendix C, No. 14).

KEPONE DEGRADATION BY PHYSICAL, CHEMICAL, AND BIOLOGICAL MEANS

Kepone is an extremely stable member of the cyclodiene insecticides and there is no evidence to date that Kepone degrades under natural conditions in the environment. Consequently, total Kepone residuals in the environment can be expected to remain relatively constant, with their distribution reflecting the natural movement of soil, sediment or organisms.

The half-life of Kepone in the environment has not been determined, but laboratory evidence suggests it may be on the order of decades. Natural photochemical degradation by sunlight was examined by Battelle (Appendix A), and in all cases sediment Kepone levels remained unchanged throughout the exposure period. Photochemical degradation will be discussed more fully in Chapter VIII.

Many destruction techniques were examined in the nonconventional mitigation examinations, but in no cases were any of the processes occurring naturally in the environment. Laboratory data imply that sediment covering and mixing, gradual solubilization, and dilution may disperse the Kepone to harmless levels over time.

Kepone Biodegradation in the Natural Environment

Practically all of the studies which have examined the possibility of Kepone degradation in the environment by microorganisms, have concluded that there is little potential for biodegradation of Kepone. Typically, these studies have examined contaminated James River sediments in the laboratory under aerobic and anaerobic conditions over extended periods of time.

Studies by Garnas, et al., and Bourquin, et al. (Appendix C, No. 12 and 10) of the Gulf Breeze Environmental Research Laboratory employed static water/sediment systems to assess both biological and non-biological degradation of Kepone. Sediments with and without Kepone contamination were taken from the James River and used in these systems. The fate of Kepone was monitored using radiolabelled Carbon 14 material and total budget chemical analysis. The investigators employed a variety of experimental conditions including oxygen concentration, nutrient additions, Kepone levels, sediment sources, sunlight, temperature, and salinity. Gulf Breeze studies indicate that Kepone does not degrade (i.e. complete recovery of Kepone after extended incubation periods) either biologically or chemically in Gulf Breeze's laboratory systems. The above data suggest that degradation processes will not significantly reduce the levels of Kepone now found in the water and sediment of the James River.

Data submitted by Allied Chemical showed essentially no decline in soil concentration after 154 days (EPA, 1975a). No evidence of microbial dehalogenation of Kepone could be found in the literature (Appendix A). Work by Vind (1976) in both aerobic and anaerobic seawater solutions over a 12-month period produced no measurable Kepone reduction.

Dr. Rita Colwell, of the University of Maryland, has grown Kepone-resistant bacteria in media made of Kepone as the nutrient. Kepone resistance appears to be plasmid mediated and resistance is dependent on exposure of the bacteria to the Kepone and possession of an extra-chromosomal Kepone resistance factor (Orndorff, et al., in press).

Dr. Ralph Valentine, of Atlantic Research Corporation, believes they have a series of fungi which will degrade Kepone. One isolate showed 41 percent disappearance of Kepone in 22 to 31 days (Appendix A). However, these experiments have been performed only in the laboratory, and no scaling-up has been attempted. These fungi probably cannot compete under natural conditions, thus their usefulness is restricted to controlled conditions.

Effects of Kepone on Estuarine Microorganisms

Results at the Gulf Breeze Environmental Research Laboratory (Appendix C) of tests with laboratory cultures and natural environmental assemblages show that Kepone is toxic to some bacteria. Kepone concentrations as low as 0.2 mg/l (ppm) significantly reduced the number of colony-forming units for James River water samples. However, since Kepone was not universally toxic, some laboratory cultures and environmental isolates survived and exhibited resistance. In toxicity studies using anaerobically grown microorganisms, Kepone was not as toxic as it was for aerobically grown microorganisms (Appendix C, No. 10).

Kepone has also been shown to affect the biodegradation potential of natural microorganisms from the James River (Appendix C). In systems containing James River sediments, the usual rate of degradation of the pesticide, methyl parathion, was reduced by 60 percent in the presence of Kepone. These studies show that Kepone could be disruptive to metabolic destruction of other organic pollutants and could alter metabolic processes in the James River estuary.

Kepone Biological Transport

Since Kepone is concentrated in animal tissues, it is subject to movement as the organism moves. Migratory fishes move into the James River to spawn and return to the Chesapeake Bay and the Atlantic Ocean. The young of these species remain in the James River until they are sufficiently grown to leave the area. Resident species stay in the river, but may move extensively within certain sections of the river during their lifetime. Finfish Kepone levels from the James River have varied greatly, with residue levels being dependent on species and length of residence for migratory fishes. Average Kepone residues in freshwater fish varied from 0.04 to 2.4 ug/g (ppm). Long-term resident estuarine finfish had mean concentrations between 0.6 and 2.7 ug/g (ppm). Short-term resident marine finfish (American shad and menhaden) showed low Kepone residues averaging less than 0.1 ug/g (ppm), while spot and croaker, which reside in the river for longer periods, had higher residues averaging 0.81 to 0.75 ug/g (ppm), respectively (Bender, et al. 1977 a).

The best available data of the many biological transport components is the commercial fish catch, but the application and interpretation of these data are complex. In the computation of the fish biomass which could contain Kepone, the following assumptions apply:

1. The limited field samples are representative of the entire catch;

2. The laboratory data are applicable to the field situation;

3. The migratory species are resident within the James River for sufficiently long to accumulate Kepone to equilibrium levels.

Using the biomass estimates of the Virginia Institute of Marine Science (Bender, 1977a), Battelle Laboratories estimated the maximum Kepone in the migratory commercial fish species of the James River to be approximately 125 kg (275 lb). In early phases of the Kepone problem, fish samples along the Atlantic coast were tested for Kepone. Levels generally were well below the present Action Levels or non-detectable (FDA, 1977). Compared to the potential of 20,000 to 40,000 pounds of Kepone in the James River, the annual removal of Kepone from the James River by migratory fishes will involve small amounts with a large dispersal of these fishes along the Atlantic coast with subsequent "dilution" of the Kepone.

DISTRIBUTION OF KEPONE

The Battelle Laboratories have conducted an intensive sampling program for Kepone in the Hopewell/Bailey Bay area (Exhibit V-2). The objective was to determine the location and quantity of Kepone deposits which might exist in the region. More than 900 samples were collected during this survey.

Bailey Bay and its Tributary Streams

The main component of the Bailey Bay sampling program was the collection of core samples of bottom sediment. Cores were obtained from all parts of the bay and analyzed for Kepone content. These results were used to establish the present distribution of Kepone throughout Bailey Bay, including its vertical profile. Cores were also collected from Bailey Creek, Poythress Run, Gravelly Run, Cattail Creek, and the western side of Tar Bay.

The results of Kepone analysis of sediment samples collected by Battelle from Bailey Bay and its major tributaries are presented in Exhibit V-3. Data represent average Kepone concentration in homogenized cores to a depth of 30 cm (12 in). Kepone was found throughout most of the bay deposited in a "Y" or yoke-shaped pattern. The tail of the yoke begins in Bailey Creek. The arms extend up the eastern and western shorelines of the Bailey Bay. The mid-bay area

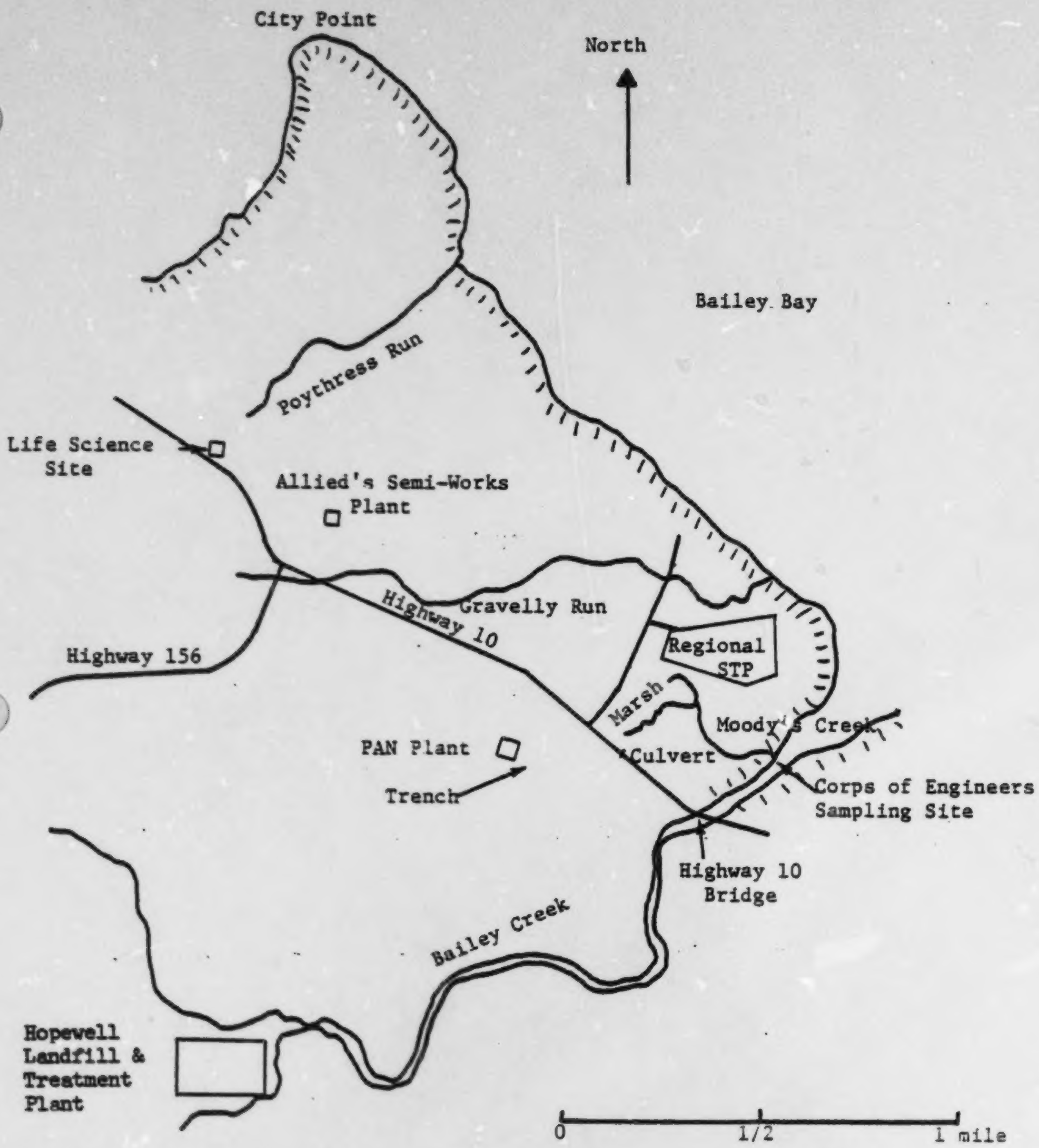
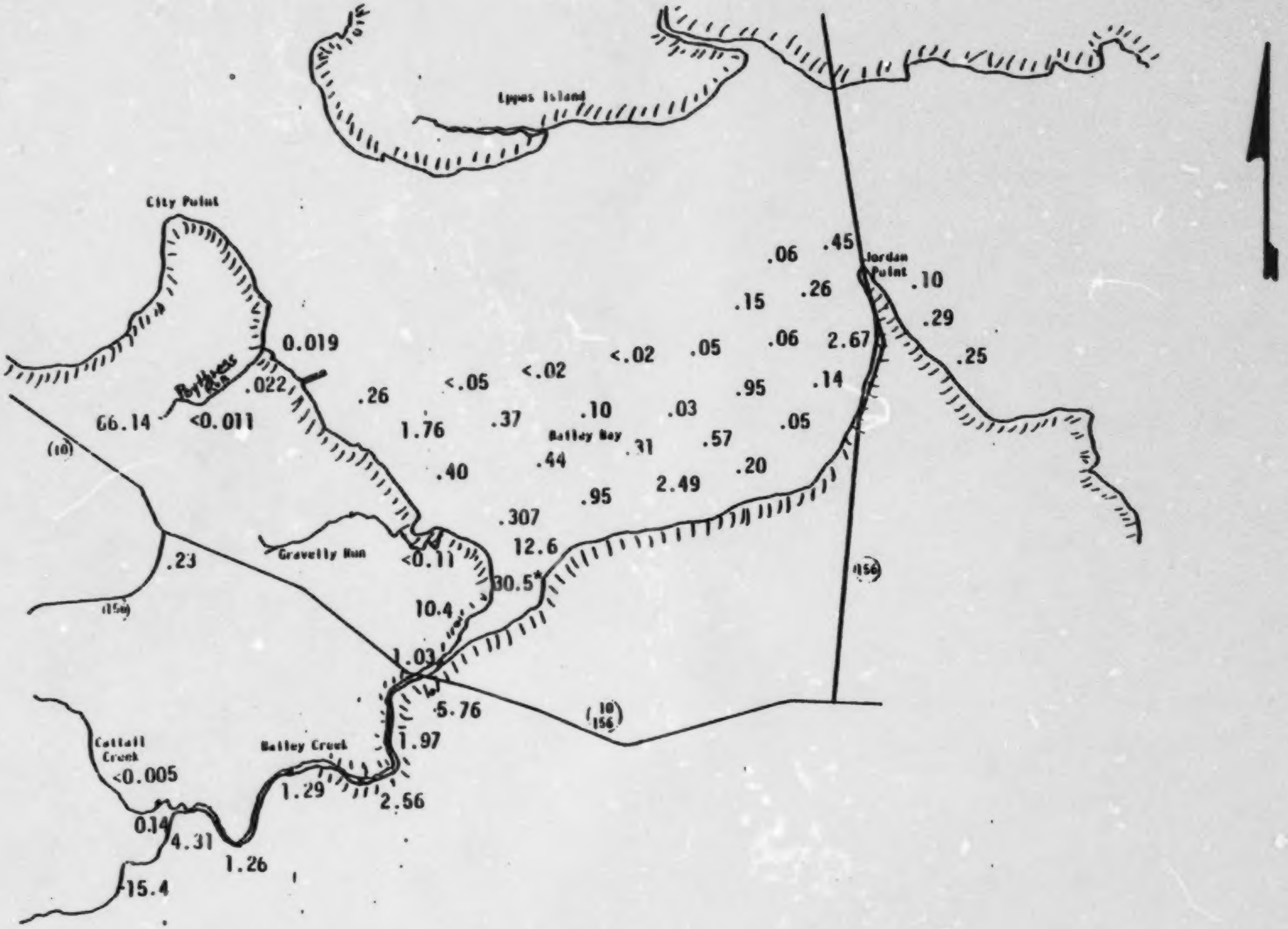

City Point
North
Bailey Bay
Poythress Run
Life Science Site
Allied's Semi-Works Plant
Gravelly Run
Highway 10
Highway 156
Regional STP
Marsh
Moody's Creek
Culvert
PAN Plant
Trench
Corps of Engineers Sampling Site
Highway 10 Bridge
Bailey Creek
Hopewell Landfill & Treatment Plant
0
1/2
1 mile

Exhibit V-2
Location of Key Features in Hopewell, Virginia


Eppes Island
City Point
Jordan Point
Bailey Bay
Gravelly Run
Bailey Creek
Cattail Creek
(10)
(156)
(10/156)
.06
.45
.10
.29
.25
.15
.26
.06
2.67
.14
<.02
.05
.95
.05
<.05
<.02
.10
.03
.57
.20
0.019
.022
.26
1.76
.37
.31
.44
.40
2.49
.95
.307
12.6
30.5*
66.14
<0.011
.23
<0.11
10.4
1.03
5.76
1.97
<0.005
1.29
2.56
0.14
4.31
1.26
15.4

*167 μg/g Kepone found at 4 in. below surface level

Exhibit V-3 Results of Kepone Analysis in Sediment Cores (μg/g-ppm)

has a markedly lower overall level of contamination. The deposition pattern coincides with the path of Bailey Creek water which is tidally influenced. Extrapolating from these data, there is estimated to be 540 kg (1,188 lb) of Kepone in Bailey Bay (Appendix A).

Kepone concentrations in sediment cores from tributaries of Bailey Bay are illustrated in Exhibit V-3. The core displaying the highest Kepone level was from the upper Poythress Run lowland which receives runoff from Nitrogen Park. No outlets exist at this lowland and hence the 66.14 ug/g (ppm) Kepone concentration reflects accumulation over time from contaminated runoff as well as possible atmospheric deposition from the Kepone production period. Other high readings, 30.5 ug/g (ppm), (167 ug/g at 4" below surface) and 12.6 ug/g (ppm) (43.5 ug/g at 6" below surface) were at the mouth of Bailey Creek. In Bailey Creek, Kepone levels increased from the Highway 156 crossing to a point just upstream of the confluence of Cattail Creek. Especially high Kepone concentrations were found in the area where landfill runoff and seeps near the disposal lagoon enter Bailey Creek. The same increase in Kepone with movement downstream is true of Cattail Creek itself.

Vertical Distribution in Sediment Cores

Kepone analyses were undertaken for vertical sections of representative cores. The results are shown in Exhibit V-4. The cores from the mouth of Bailey Creek, the western shore, and Jordan Point display a bell-like distribution, with the maximum concentration of Kepone occurring at four to eight inches below the surface. There are several possibilities for this type of distribution. It is possible that the Kepone deposition at depth corresponds to the maximum production and subsequent decline of Kepone production by Life Science Products, but this would have meant an extremely high sediment deposition rate. Another hypothesis is that Kepone could have been lost from surface layers through desorption. Flowing water over the bottom could have extracted the Kepone and carried it downstream. Neither supposition has been adequately proven, but the latter corresponds well with subsequent model results which showed 65 to 70 percent of Kepone movement in the James River to be the result of solubilized Kepone. The cores from the middle of Bailey Bay and Tar Bay have high surface contamination levels which rapidly decline with depth, but these are also areas outside of the main flow of the channel.

Exhibit V-4

KEPONE DISTRIBUTION IN SEDIMENT CORES WITH DEPTH (ppm)

Depth from Surface (in.)	Bailey Creek Above Route 10 Bridge	Bailey Creek Mouth	Bailey Creek Mouth	Gravelly Run Mouth	Midway Poythress and Gravelly Runs	Mid Bailey Bay	Bailey Bay Jordan Pt.	Tar Bay Jordan Pt.
1	0.81	1.36	9.44	<0.34	0.11	0.19	0.95	1.09
2	0.59	1.66	10.55	<0.10	0.13	0.03	0.86	1.27
3	1.30	2.54	46.53	<0.05	<0.08	0.03	0.87	0.42
4	0.78	3.88	167.0	<0.09	0.15	0.01	0.87	0.03
5	16.46	14.07	102.0	<0.09	0.92	0.01	1.25	0.02
6	2.91	40.74	18.34	<0.10	0.80	0.03	3.63	<0.01
7	65.14	42.29	5.12	<0.06	0.30	<0.01	17.80	<0.01
8	19.17	13.87	0.55	<0.06	<0.04	<0.01	0.17	<0.02
9	0.90	4.34	0.41		<0.03	<0.01	0.16	<0.01
10	0.45	0.86	0.37		<0.03	<0.01	0.14	<0.02
11		<0.51	0.31					
12		<0.42	0.36					
13		<0.19	0.38					
14		<0.10	0.14					
15		<0.14						
16		<0.04						

Organic Preference

Sediments sampled by Battelle from three locations around Bailey Bay were analyzed for Kepone concentration and there appears to be a correlation between Kepone concentration, organic content, and particle size. Kepone is preferentially associated with the larger organic particles in the sediment and this observation coincides with those made by Allied Chemical (Williams, 1977) and by the Virginia Institute of Marine Science (Appendix C, No. 16). This correlation suggests that detrital matter has an important role in the binding and transport of Kepone.

Kepone Distribution in the Hopewell Area

Production Area Runoff

Runoff sampling was conducted by Battelle at the Life Science Products plant site on May 4, 1977, when 5.8 cm (2.3 in) of precipitation fell on the City of Hopewell. Runoff samples collected at the Life Science Products site had elevated Kepone concentrations of 387 and 394 ug/l (ppb).

Runoff samples were also collected in the area of the Allied Chemical Semi-Works plant. On August 7, 1977 after a rainfall of 0.25 cm (0.1 in) standing water on the site was found to contain

54.1 ug/l (ppb) Kepone. Water discharging from a nearby drainpipe into Gravelly Run contained 3.38 ug/l (ppb) Kepone. A second detailed sampling of overland runoff was conducted in November in the open areas in the neighborhood of the former plant site. Sample locations and Kepone levels are shown in Exhibit V-5. Runoff samples showed a sample from the Life Science Products site to contain 687 ug/l (ppb), while other samples further away ranged from 1.08 to 96.6 ug/l (ppb).

Overland Runoff

To estimate the effect of runoff on Kepone movement, a series of water samples was taken by Battelle along creeks in the area during low flow (May 19, 1977) and runoff conditions (May 16, September 7, October 3, 1977). The results of subsequent Kepone analyses are presented in Exhibit V-6. In all cases, high runoff conditions in the creeks increased the total Kepone concentration over those observed during low flow with the possible exception of the mouth of Gravelly Run, where both samples were extremely low.

A second set of Bailey Creek water samples was collected on January 12 and 13, 1978 to delineate Kepone transport in that area. The results of this analysis were compared with earlier data and conditions in the creek. Highest Kepone concentrations occurred on days when runoff was heavy. At the mouth, the effect is most notable during slack tide. The January 12, 1978 flood tide sample at the

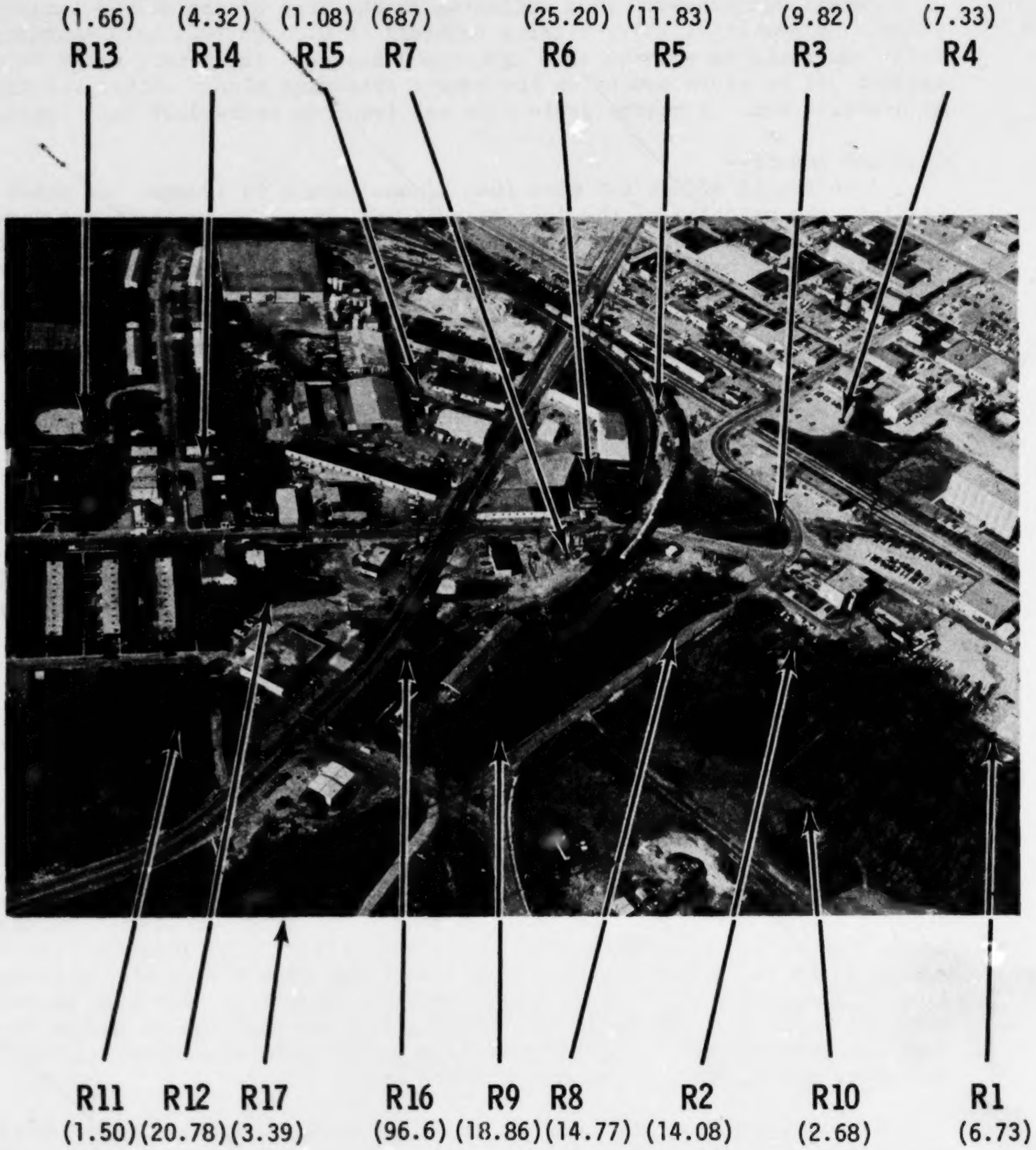

(1.66) R13
(4.32) R14
(1.08) R15
(687) R7
(25.20) R6
(11.83) R5
(9.82) R3
(7.33) R4
R11 (1.50)
R12 (20.78)
R17 (3.39)
R16 (96.6)
R9 (18.86)
R8 (14.77)
R2 (14.08)
R10 (2.68)
R1 (6.73)

EXHIBIT V-5 Runoff Sampling Locations and Kepone Concentrations in Open Areas Around the Life Science Site November 29, 1977 (μg/ℓ-ppb)

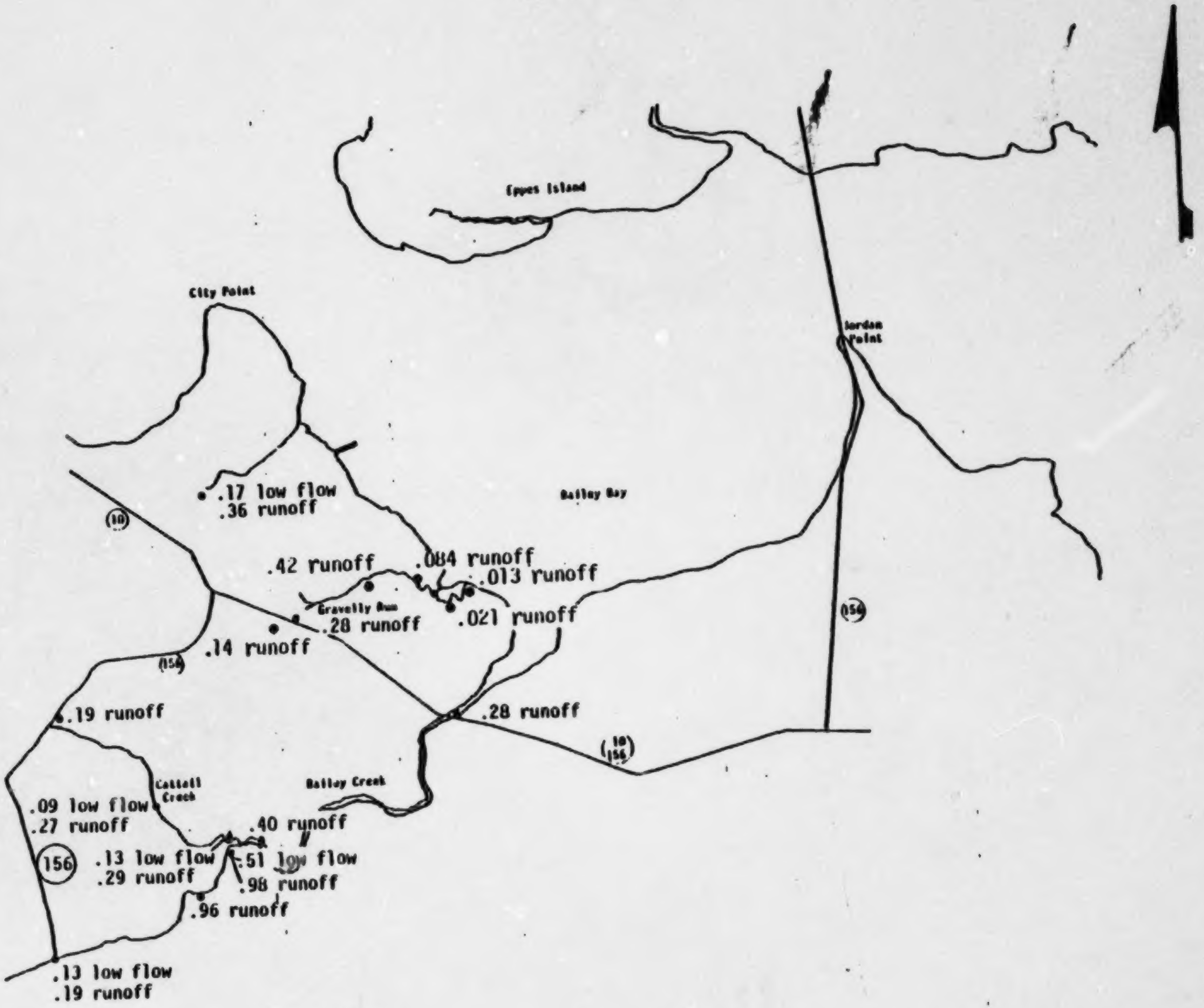

Eppes Island
City Point
Jordan Point
Bailey Bay
.17 low flow
.36 runoff
(10)
.42 runoff
.084 runoff
.013 runoff
Gravelly Run
.28 runoff
.021 runoff
(156)
.14 runoff
(156)
.19 runoff
.28 runoff
(10/156)
Cattail Creek
Bailey Creek
.09 low flow
.27 runoff
.40 runoff
156
.13 low flow
.29 runoff
.51 low flow
.98 runoff
.96 runoff
.13 low flow
.19 runoff

Exhibit V-6

Effect of Runoff on Movement of Kepone in Hopewell Area Concentrations in μg/ℓ (ppb) mouth suggested that water from Bailey Bay did not affect Kepone concentrations. The effect of varying pH levels cannot be fully assessed. The high pH values were all found near the mouth and consequently, the high Kepone levels in that same area may reflect higher solubilities under these conditions.

An approximation of the total quantity of Kepone transported from streams during low flow and runoff conditions was made using these data and data for streamflow at the point of sampling. These data indicate that during high flow periods, there is approximately 20 times the Kepone discharged per day as there is during dry weather flow. An observation which must temper this conclusion is that there are many seeps and nonpoint sources which could add to the total Kepone burden in Bailey Bay. It is also important that these tributaries are tidally influenced so some Kepone may be cycled back to Bailey Creek with incoming tides.

In general, Kepone concentrations in runoff are highest near the Life Science Products plant site and decline as one moves outward. From these values and the stream data, an estimated 64 grams (0.14 lb) per day of Kepone is transported to the James River system from the Hopewell area during average periods of rainfall. During dry times, the total is 3 to 4 g/day (Appendix A).

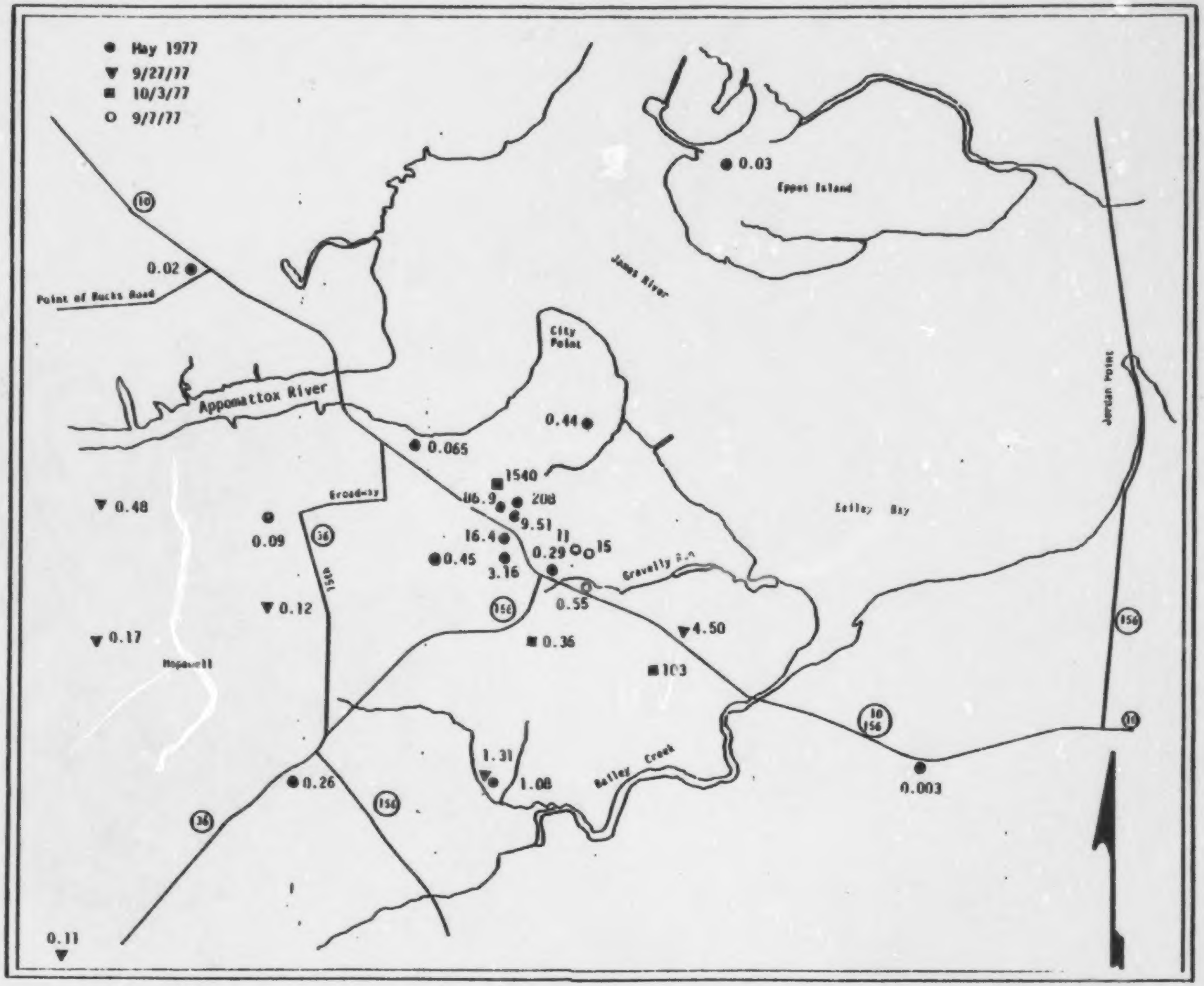
Groundwater

In May 1977, groundwater samples were collected from three private wells and eight State Water Control Board (SWCB) monitoring wells. All wells tested were shallow and penetrated only localized groundwater sources. Detectable levels of Kepone were restricted to three wells: the monitoring well near the Kepone Pit at the Hopewell sanitary landfill (0.24 ug/l-ppb), the south monitoring well at the Kepone/sludge lagoon (0.81 ug/l-ppb), and the J.W. Quick private well (0.08 ug/l-ppb).

Soils

The runoff data of Battelle revealed that portions of the Hopewell area still contributed Kepone to the James River via uptake from soil surfaces. Data from a sampling of surface soils from around the Hopewell area are presented in Exhibit V-7. Detectable levels of Kepone were found at all stations including one station on Eppes Island across the James River and one across the Appomattox River.

Kepone concentrations in soil were generally found to increase at stations located nearest the site of the Life Science Products plant as might be expected. Samples taken in the vicinity around the plant had from 1.91 to 938 ug/g (ppm) Kepone. A single sample from the northwest corner of the plant site was found to contain 1,540 ug/g


● May 1977
▼ 9/27/77
■ 10/3/77
○ 9/7/77
10
0.02
Point of Bucks Road
Appomattox River
0.065
0.03
Eppes Island
James River
City Point
0.44
1540
86.9
208
9.51
11
15
16.4
0.29
0.45
3.16
Gravelly Run
0.55
156
0.36
4.50
103
Broadway
0.48
0.09
36
15th
0.12
0.17
Hopewell
Bailey Bay
Jordan Point
156
10
156
10
0.003
1.31
1.08
Bailey Creek
0.26
156
36
0.11

Results of Soil Analysis in Hopewell Area (µg/g-ppm)
Exhibit V-7

(ppm). This area had been used for storage and did not appear to have been cleaned with the rest of the site. Soil samples away from the Life Science Products site on the perimeter of the city averaged 0.1 ug/g (ppm) (Exhibit V-8).

Surface soil levels in Nitrogen Park were 9.19, 29.2, 30.2, 104 and 770 ug/g (ppm). A vertical analysis at one sample site in Nitrogen Park revealed the following Kepone concentration changes with depth:

Depth (in.)	Kepone Concentration ug/g (ppm)
1	29.2
2	0.76
3	0.35
4	0.31
5	0.097
6	0.060
7	0.038
8	0.091
9	0.23
10	0.80

The vertical distribution of Kepone in the soil of Nitrogen Park suggests that Kepone has migrated from the upper layers and has become concentrated at the eight to ten inch level. No explanation has been found for the Kepone concentration at this level.

Several other sites were sampled at depth to ascertain if percolation of Kepone was widespread. These samples were similar to

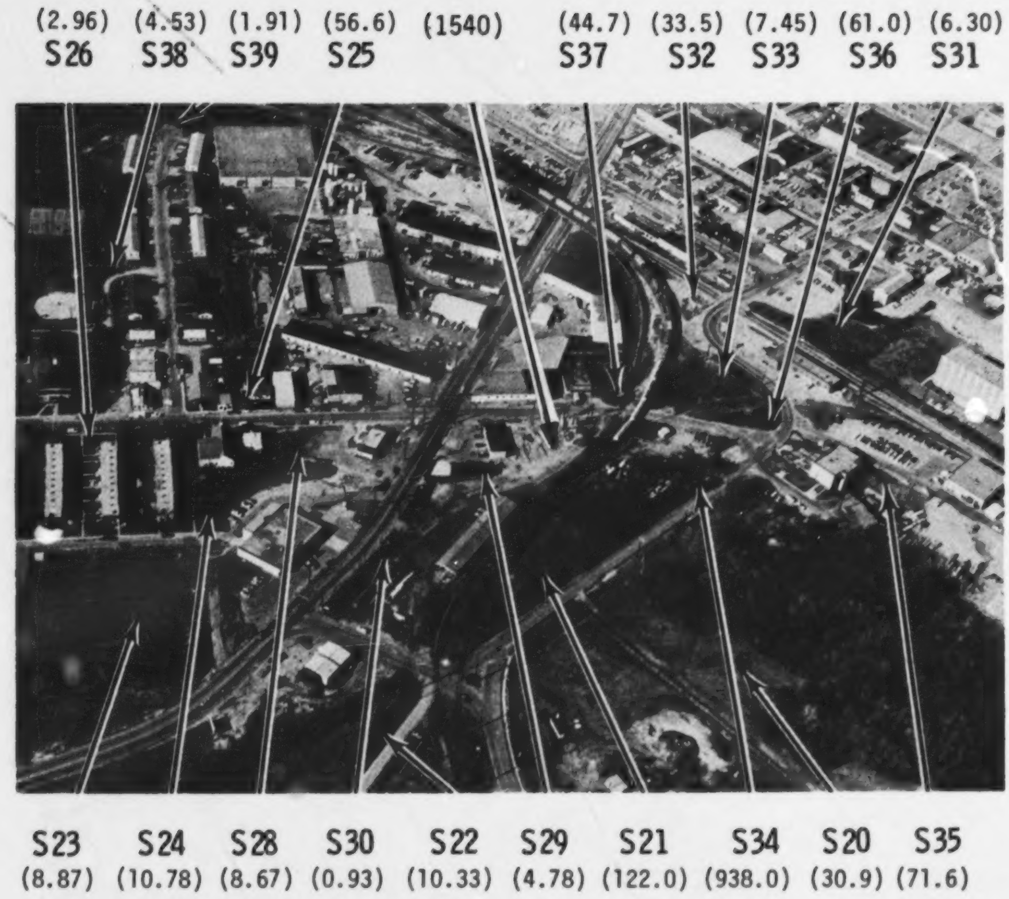

(2.96) S26
(4.53) S38
(1.91) S39
(56.6) S25
(1540)
(44.7) S37
(33.5) S32
(7.45) S33
(61.0) S36
(6.30) S31
S23 (8.87)
S24 (10.78)
S28 (8.67)
S30 (0.93)
S22 (10.33)
S29 (4.78)
S21 (122.0)
S34 (938.0)
S20 (30.9)
S35 (71.6)

EXHIBIT V-8 Soil Sampling Locations and Kepone Concentrations in Open Areas Around the Life Science Site (2/4/78) (µg/g-ppm)

those from Nitrogen Park in that Kepone concentrations dropped an order of magnitude from the first to the second inch of surface soil.

Previous data reported by the Virginia State Water Control Board of cores collected while drilling a monitoring well in Nitrogen Park had indicated Kepone as low as 6.1 meters (20 ft) below the surface. Consequently, hand-augered cores were collected by Battelle at two sites to determine the distribution with depth. Kepone was detectable to a depth of 3.05 m (10 ft). At both locations, concentrations were found to increase measurably at the 1.8 to 2.5 meters (6 to 8 ft) zone, reaching a Kepone concentration as high as 0.062 ug/g (ppm). This unequal distribution in the soil column may represent differences in sorption by various soil strata, or it may coincide with vertical movement of Kepone from the surface.

Hopewell Sewer System

Influent Kepone levels at the Hopewell treatment plant were measured by Battelle at 0.77 and 0.44 ug/l (ppb), while the effluent contained 0.57 and 0.49 ug/l (ppb) Kepone. It is clear that Kepone was either never completely cleaned from the system or is still entering the Hopewell sewer system and subsequently being discharged in treatment plant effluent. Surveys of major sewer trunklines were conducted to determine the geographical distribution of Kepone inflow sources. Results of these wastewater and slime samples from all pump stations and manholes tested were found to have measurable Kepone concentrations ranging from 0.085 to 4.88 ug/l (ppb). Slimes ranged between 0.12 and 118 ug/g (ppm). The 118 ug/g figure was detected at the main pump station.

It is hypothesized that the Kepone present was adsorbed or otherwise accumulated by the slime from Kepone inflows during the Life Science Products production of 1974-1975. Currently, these deposits help maintain the levels of Kepone found in wastewater. This may occur when Kepone-contaminated growth breaks away from the walls and enters the sewage as suspended solids or it may occur through desorption of the Kepone from the slime. Recent levels of 0.5 ug/l (ppb) account for an average Kepone effluent discharge of 5.69 grams per day. Higher Kepone concentrations occur periodically as a function of increased precipitation. During periods of high runoff, daily Kepone discharges were found to be 37.6 grams. This is over six times the dry weather contribution. The effluent from the Hopewell primary treatment plant now flows to the new Regional treatment plant where Kepone may well be removed through sorption on sludge. Consequently, the above calculated inputs of Kepone to the James River may be reduced or eliminated.

Pebbled Ammonium Nitrate Plant Site

Little has been reported about the disposal of Kepone and related wastes in the vicinity of Hopewell. In the latter part of 1974, pressure was exerted on Life Science Products to reduce the amount of Kepone discharged from its facilities into the city sewer system. The State Water Control Board discovered that Kepone was interfering with the digesters at the Hopewell treatment plant (Senate Hearings, 1976). As a result, Life Science Products looked for alternative means for disposing of its contaminated wastewater. In December of 1974, discharge of wastewater began at the site of the Pebbled Ammonium Nitrate (PAN) plant.

The PAN site lies along the southern edge of the State Highway 10, approximately one-half mile west of Bailey Creek. It is relatively isolated in an industrial area of town. In 1970 Allied Chemical sold the deserted plant and site, which was subsequently used by Greenbank Services, Inc. for salvage, storage, office space, and sand quarrying.

The 6.1 meter (20 ft) wide trench into which the wastewater was discharged measured roughly 1.2 meters (4 ft) deep by 11 meters (35 ft) long. It lay above a steep ravine where drainage flowed outward through a culvert under Highway 10 into a marsh. Water flows in a northerly direction through the marsh for approximately one quarter mile, then turns east and joins Bailey Creek below the Highway 10 bridge.

There are no good estimates currently for either the amount of Life Science Products wastewater discharged into the trench or the water's concentration of Kepone. It is known that the trench received wastewater on a regular basis, perhaps daily, from December 1974 into the summer of 1975. A single homogenized core from 1976 State Water Control Board (unpublished data) showed nearly 3 percent Kepone (27,325 ug/g-ppm).

Battelle sampled the PAN site on October 3, 1977 and November 22, 1977. These data showed Kepone-contaminated soil in the area of the trench, with highest levels found at 4 feet (1,863 ug/g-ppm). Apparent horizontal movement in the surface soil occurred in the natural drainage direction with surface samples downstream reaching 84.3 ug/g (ppm) Kepone. Samples taken on the west face of the quarry pit revealed very low Kepone levels with no real variation with depth.

After review of data, auger samples were supplemented with deep core drilling of 15 meters (50 ft) and hand core sampling. Some of these sample locations and subsequent results are presented in Exhibit V-9. A variability of nearly three orders of magnitude was found at the sites. Values of Kepone concentration for the cores ranged from

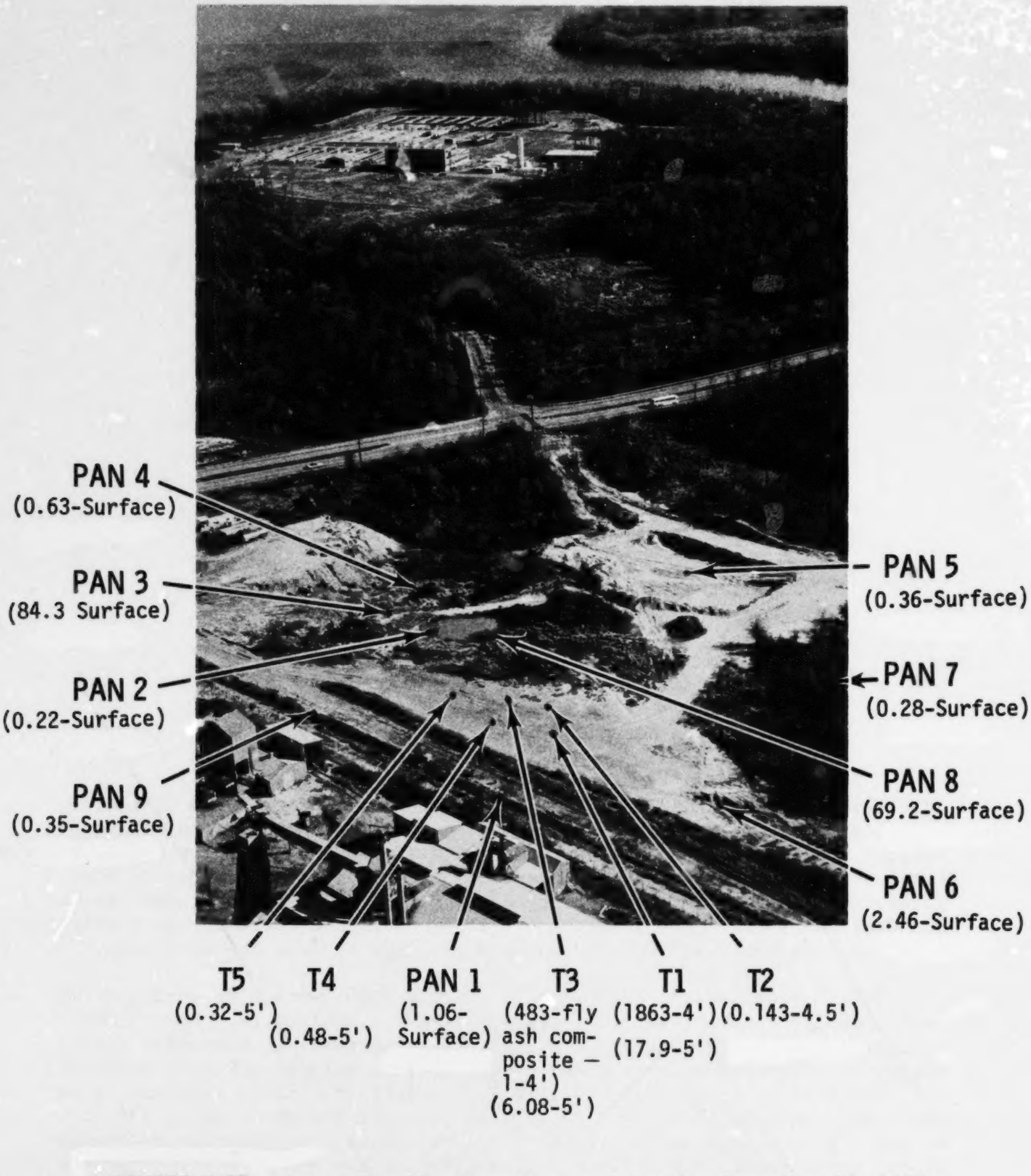

PAN 4
(0.63-Surface)
PAN 3
(84.3 Surface)
PAN 2
(0.22-Surface)
PAN 9
(0.35-Surface)
PAN 5
(0.36-Surface)
PAN 7
(0.28-Surface)
PAN 8
(69.2-Surface)
PAN 6
(2.46-Surface)
T5
(0.32-5')
T4
(0.48-5')
PAN 1
(1.06-Surface)
T3
(483-fly ash composite — 1-4')
(6.08-5')
T1
(1863-4')
(17.9-5')
T2
(0.143-4.5')

EXHIBIT V-9 Auger Sampling Locations and Results November 23, 1977 (µg/g-ppm) (Depth in feet of sample follows results.)

0.001 to 6.13 ug/g (ppm) with two-thirds of the readings below 0.050 ug/g (ppm). Only three concentrations exceeded 1.0 ug/g (ppm).

Strata from some of the cores were also analyzed for hexachlorocyclopentadiene (HCP). Hexachlorocyclopentadiene residuals were approximately comparable to those for Kepone, except for one core where as much as 192 ug/g (ppm) HCP were found at 5.8 to 6.1 m (19 to 20 ft).

Water samples were collected by Battelle from several locations at the PAN site during a rainstorm. Results of the sampling showed the highest level of Kepone (89.35 ug/l) originated from the disposal trench area and flowed into the small reservoir behind an earthen dam. All other runoff also contained Kepone levels from 0.13 to 7.04 ug/g (ppm).

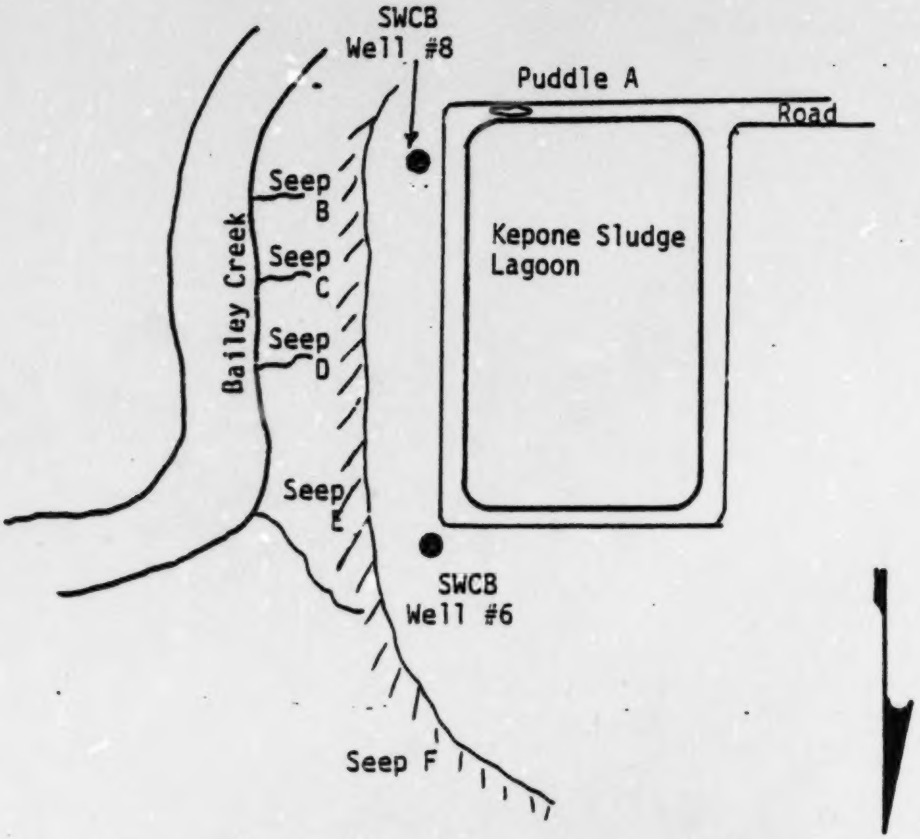
From the data collected at the PAN site, Battelle estimated the quantity of Kepone in the disposal trench (37 m^2-400 ft^2) would not exceed 100 kg (220 lb), while HCP was estimated at 23 kg (50 lb). Both Kepone and HCP in one core showed marked concentration increases between 6.1 meters (20 ft) and 10.7 meters (35 ft), suggesting horizontal movement within that layer.

Cores were also taken in the marsh and bed of Moody's Creek, which receives runoff from the PAN site. Results did not indicate the presence of any major zone of Kepone in the Moody's Creek drainage.

The Kepone/Sludge Lagoon

As noted earlier, a 4,140 m³ (1.1 million gal) lagoon was constructed to hold contaminated sludge from the Hopewell treatment plant digesters. The lagoon is a 33.5 meters (110 ft) by 58 meters (190 ft) rectangular holding pond formed by earthen dikes. It has a maximum depth of 2.13 meters (7 ft) and is reportedly lined with a layer of clay and two layers of gravel impregnated with asphaltic material (Koener, et al. 1976). The potential that this lagoon could contribute Kepone-contaminated leachate to Bailey Creek led to a series of investigations by Battelle throughout the spring of 1977. Initially, attention was paid to the monitoring of seeps discovered in the area (Exhibits V-10, 11).

Additional water samples were taken on August 15, 1977 from the lagoon, the marsh seep E, seep C, monitoring well No. 5 in the landfill just upgradient from the lagoon and the monitoring well (No. 8) at the south end of the lagoon. These were then subjected to a series of chemical analyses to determine if further evidence could link water in the lagoon to that discharged by the seeps.


SWCB
Well #8
Puddle A
Road
Seep B
Seep C
Seep D
Bailey Creek
Kepone Sludge Lagoon
Seep E
SWCB
Well #6
Seep F

A - Mud Puddle in road - apparent seepage into this puddle.
B - Seep into creek out of hill side, <0.1 cfs.
C - Small seep, wet ground, no noticeable above ground flow.
D - Seep into creek from hillside, 0.1-0.2 cfs.
E - Seep or flow from marsh, upstream from sewage outflow but could be influenced by it.

Location of Sample Sites Around Kepone Sludge Lagoon

Exhibit V-10

Exhibit V-11 KEPONE LEVELS IN THE VICINITY OF THE SLUDGE LAGOON

Location	Kepone Concentration		Centrate	Soil	Sept. 6	September	Nov. 11
	May 28 (µg/ℓ-ppb)	July 8 (µg/ℓ-ppb)	July 8 (µg/ℓ-ppb)	July 8 (µg/g-ppm)	(µg/ℓ-ppb)	(µg/ℓ-ppb)	(µg/ℓ-ppb)
A-Puddle in Road	5.28			.17, .09 - Dike high, low			
B-Seep Near Creek <0.1 cfs	0.84	0.40	0.47	.03			
C-Moist Patch at Base of Hill	0.20				.01		
D-Seep at Base, 0.1-0.2 cfs	0.22	<.12	<.17				
E-Seep in Marsh Area, .5 ℓ/sec	17.40	18.38	18.43	3.88	9.57	$73.5^{\#}$ 361^{*}	
F-Seep Beneath Bank						77.3^{*}	26.39
Lagoon	97.50		213			41.5^{+}	

# - Sampled 9-15
+ - Sampled 9-16
* - Sampled 9-28

Results of Kepone analysis showed all seeps had detectable levels of Kepone; B and E exceeded levels measured in the monitoring well on the south corner of the lagoon. They are also much higher than the 0.05 ug/l (ppb) detected in the same seeps by State officials in 1976 (SWCB, 1976a). Centrifuging did not reduce the Kepone levels and, hence, they appear to result from the dissolved form rather than particulate Kepone or Kepone sorbed onto particles. Desorption tests with contaminated soil in the area of the seep produced no more than 0.72 ug/l (ppb) after 90 days contact.

Samples taken in September revealed much higher levels of contamination, including 77.3 ug/l (ppb) Kepone in a new seep (F) discovered at the base of the embankment below the lagoon and a value of 361 ug/l (ppb) Kepone from the source of seep E.

From the parameters measured, Battelle concluded that a link exists between the two water sources: the lagoon and seep E. In addition to the previously discussed correlation in Kepone values, there are significantly higher concentrations of phosphate, chloride, fluoride, conductivity, antimony, hardness, pH, and alkalinity in these two samples than in any of the other (Exhibit V-12). Indeed, of the parameters tested, only sulfate and nitrate did not correspond. All paramters would not be expected to reflect the same dilution ratios since varying levels of interaction with the soil would be expected. Hence, phosphate, which often precipitates out in soil, may

Exhibit V-12

COMPARATIVE VALUES FOR COMPONENTS FOUND IN THE KEPONE/SLUDGE LAGOON, SEEPS, AND NEARBY WATER

Site	ppm SO_4	ppm PO_4 Total	ppm Cl^-	ppm F^-	ppb Kepone[a]	micro mhos/cm Conductivity	ppb Antimony	ppm NO_3-N	ppm Hardness	pH	ppm Alkalinity
1. Lagoon	3.75	22.5	42	1.35	213	1,220	57	5.3	136	7.9	360
2. Marsh Seep No. E	256	3.5	16.5	.68	18.43	1,080	77	<1	118	7.7	114
3. Main Seep No. C	110	.76	5.0	.17	<.17	600	<16	6.4	84	6.6	40
4. Landfill Well	<1	.57	2.0	.17		250	<16	1.8	58	7.2	88
5. Pond Well	<1	.73	3.5	.17		240	<16	<1	52	7.2	84

---

[a] Data from samples of July 8.

appear to be more effectively diluted than chloride which is quite mobile.

From the above analysis, there is good probability that Kepone is leaking from the Kepone/sludge lagoon. Kepone concentrations in seeps are markedly higher than reported in 1976, and those for E exceed all levels in the creek, sewage treatment plant outfall, and other potential sources of Kepone. However, it should be noted that clandestine dumping in the area could have occurred, thus feeding leachate without input from the lagoon.

Hopewell Landfill

Records and statements by former Life Science Products employees have revealed that Kepone-contaminated residues were discharged at the Hopewell landfill. While some disposal locations are well known, little has been reported on their contents, and no single authority has accumulated a composite picture of where all the sites were within the landfill, when they were in use, and what they received. Locational information has been gathered and summarized in Exhibit V-13.

The Life Science Products plant burial pit is the site where 2,100 m^3 (2,300 yd^3) of rubble from dismantling the facility were buried and marked with a permanent plaque. The miscellaneous waste

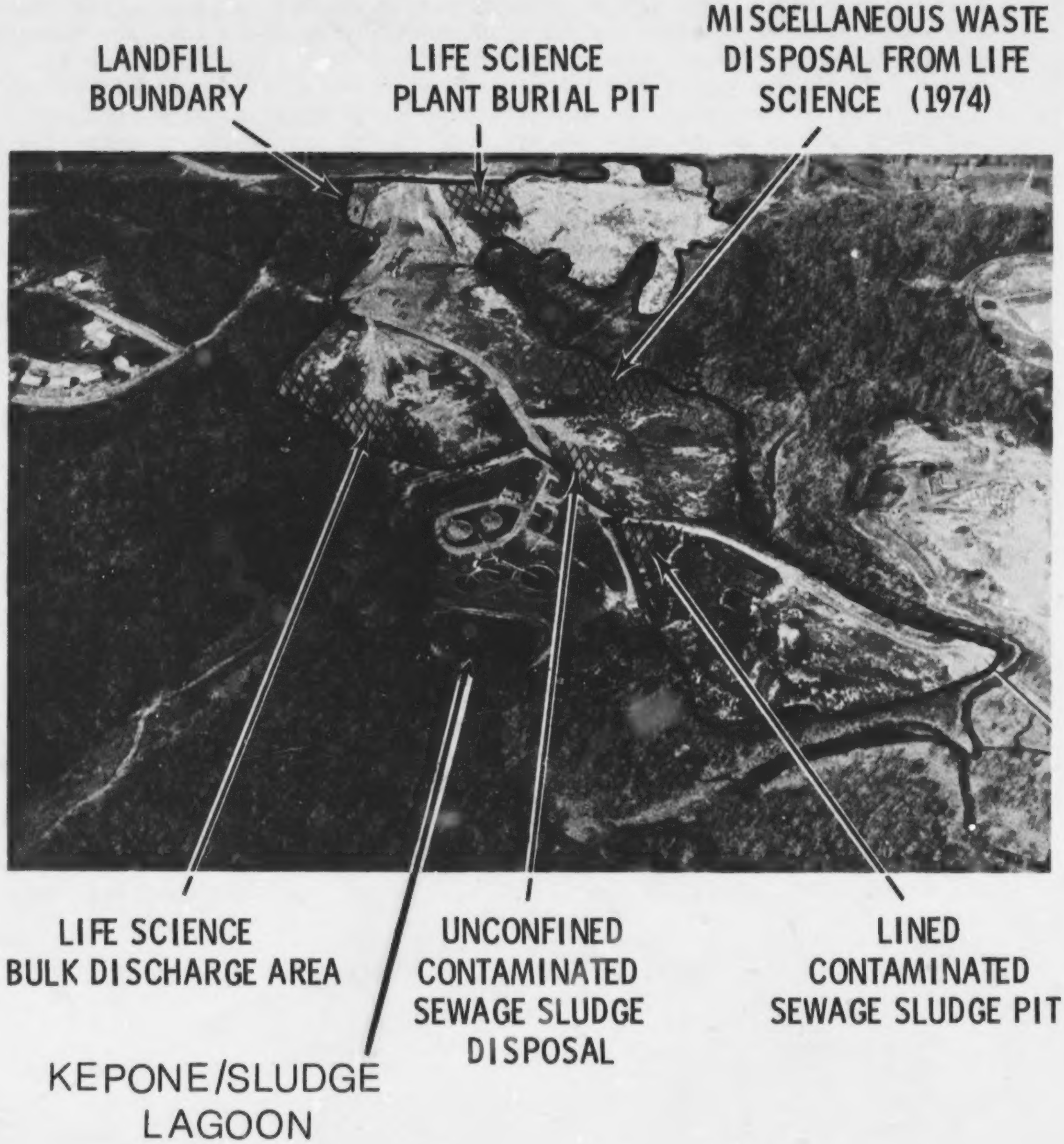
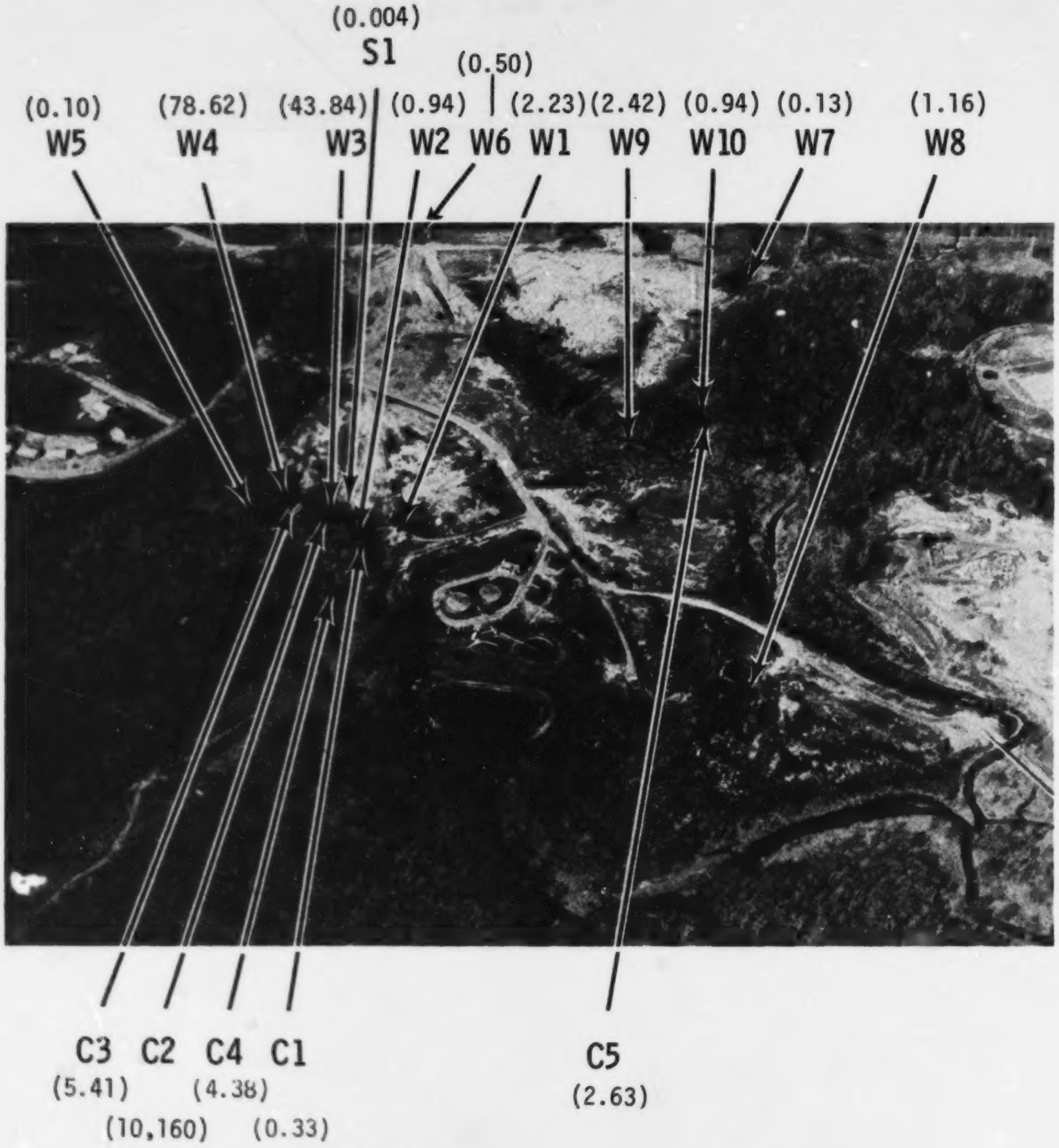

LANDFILL BOUNDARY
LIFE SCIENCE PLANT BURIAL PIT
MISCELLANEOUS WASTE DISPOSAL FROM LIFE SCIENCE (1974)
LIFE SCIENCE BULK DISCHARGE AREA
UNCONFINED CONTAMINATED SEWAGE SLUDGE DISPOSAL
LINED CONTAMINATED SEWAGE SLUDGE PIT
KEPONE/SLUDGE LAGOON

EXHIBIT V-13 Known and Suspected Deposits of Kepone in the Hopewell Landfill

disposal site was utilized during 1974 for plant wastes from Life Science Products. This included refuse and it is unknown what amounts of Kepone, if any, were deposited there. The Bulk Discharge Area is a general zone thought to have received a bulk discharge of Kepone.

Testimony on file at the State Attorney General's office indicates that in late October 1974, oil entered the quench tank at Life Science Products. Two spetic tank cleaning trucks were brought in to pump out several loads apiece. These were discharged at the head of an embankment at the landfill and were allowed to run down into an adjacent marsh. On November 30, 1977 a series of water samples and cores were collected by Battelle to identify significant Kepone outflows from the landfill. Runoff samples revealed elevated Kepone concentrations below the bulk discharge disposal site. Samples from other suspected or known disposal sites have measurable Kepone levels, but these are comparable to values detected throughout the Hopewell area and, therefore, do not display surface contamination different from that of nondisposal areas. Of the remaining sites, only two had runoff with Kepone in excess of 1 ug/l (ppb): one below the miscellaneous waste disposal area, and one from the lined sewage sludge disposal pit. No runoff sample was taken in the area around the unconfined sewage sludge disposal site.

Results of Kepone analysis for 30 centimeter (12 in) cores from the landfill site are presented in Exhibit V-14. The bulk of the


(0.004)
S1
(0.50)
(0.10)
W5
(78.62)
W4
(43.84)
W3
(0.94)
W2
W6
(2.23)
W1
(2.42)
W9
(0.94)
W10
(0.13)
W7
(1.16)
W8
C3
(5.41)
C2
(10,160)
C4
(4.38)
C1
(0.33)
C5
(2.63)

W - Water samples in µg/l (ppb) Kepone
S - Soil sample in µg/g (ppm) Kepone
C - Core samples in µg/g (ppm) Kepone

EXHIBIT V-14 Landfill Sampling Locations and Results of Kepone Analysis
November 30, 1977

contamination occurs in the top 10 centimeters (4 in) of soil. One sample, the C2 site, exceeded 1 percent Kepone (10,160 ug/g-ppm). This site corresponds with the high runoff values identified and reflects an area of major discharge. Additional sampling was performed to determine the extent of contamination in the marsh area.

Concentrations of Kepone found in the surface sediments of the marsh samples are presented in Exhibit V-15. These ranged from a low of 2.2 ug/g (ppm) to a high of 35,163 ug/g (ppm). A pentagonal section approximately 1,000 m^2 (0.25 acre) in area contains sediments averaging 12,200 ug/g (ppm) or 1.2 percent Kepone in the top 4 inches. Variations in Kepone concentrations with depth occurs. Kepone concentrations below an average of a 4-in. depth are roughly an order of magnitude less and quickly drop to levels in the tens of parts per million range. Based on 1,000 m^2 (0.25 acre) of sediments (1,122 kg/m^3, 70 lb/ft^3 dry) contaminated to an average level of 12,200 ug/g (ppm) in the top 10 cm (4 in.), it is estimated that 1,400 kg (3,100 lb) of Kepone currently lie in the marsh. This is 78 percent of the estimated 1,800 kg (4,000 lb) that were released into the Bulk Discharge Area.

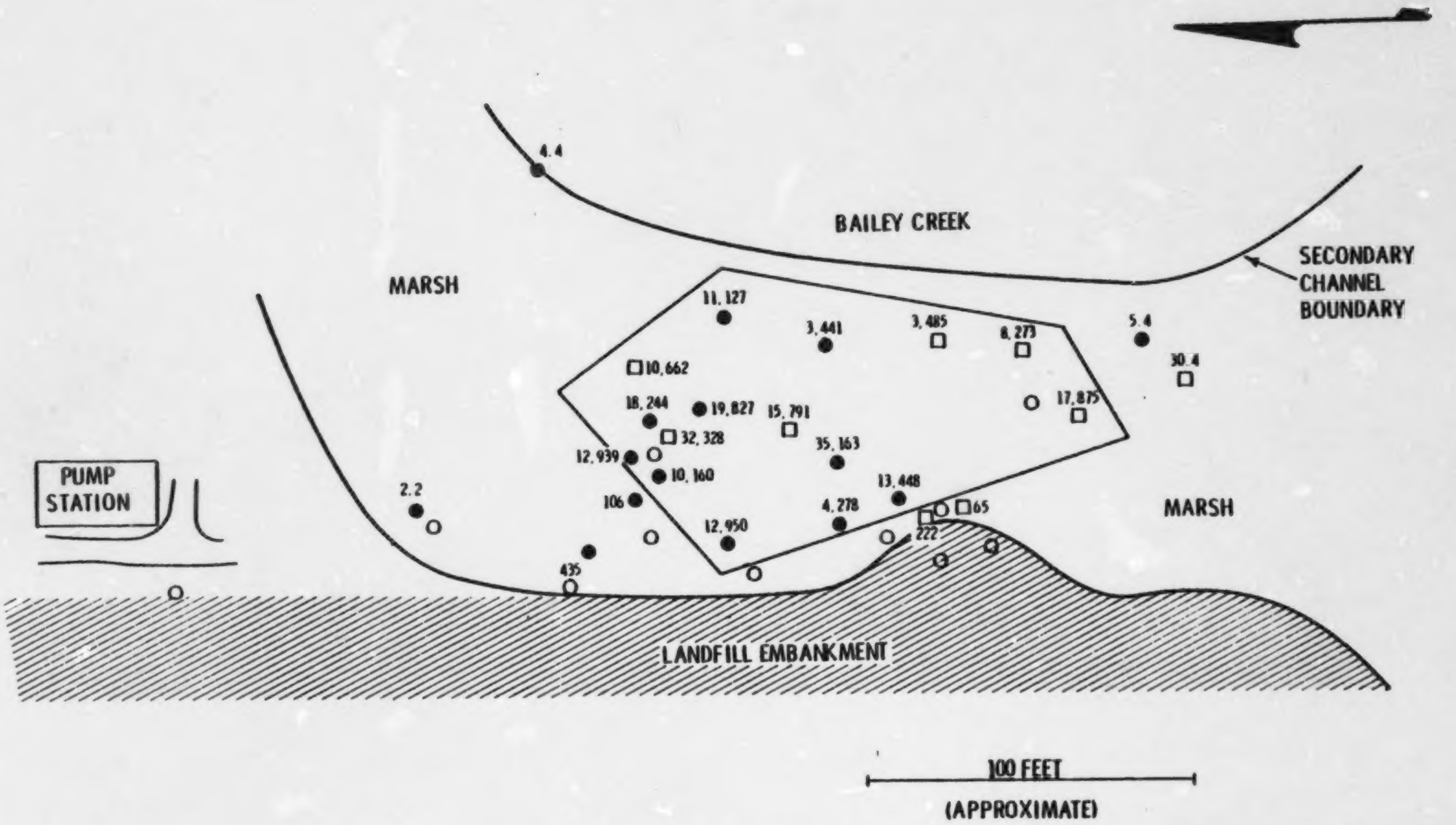

4.4
BAILEY CREEK
SECONDARY CHANNEL BOUNDARY
MARSH
11,127
3,441
3,485
8,273
5.4
30.4
10,662
18,244
19,827
15,791
17,875
32,328
35,163
12,939
10,160
13,448
2.2
106
4,278
65
12,950
222
435
PUMP STATION
MARSH
LANDFILL EMBANKMENT
100 FEET
(APPROXIMATE)

Exhibit V-15
Kepone Levels in Surface Sediment of Marsh and Approximate Boundary of Heavy Contamination

James River

Field Sampling Program

Sorption-desorption kinetics and the affinity of Kepone for organic particles suggested that sediments played a key role in the movement of Kepone in the James River. Sediment transport was modeled to quantify Kepone movement and to determine the fate of Kepone residuals. To achieve this, Battelle conducted a field sampling program on June 25-28, 1977, which was complemented by a survey by VIMS in August 1977. The purpose of the sampling program was to obtain data on the James River for input to and calibration of Battelle's sediment and contaminant transport model (FETRA), as well as to provide data for the further assessment of Kepone contamination in the James River. One of the major objectives of the program was to observe the longitudinal, lateral, and vertical variations in the measured parameters and to make a qualitative judgment on the importance of the magnitude of these variations during the sampling program. Thus, the field sampling program was confined to a relatively short period of time and the number of transects and stations was limited.

The sampling program consisted of data acquisition at eleven transects from the James River Bridge near Newport News to City Point at Hopewell. Three stations were located on each transect and one to three depths were sampled per station for each of three tidal conditions (flood, slack and ebb). The locations of these stations are listed below and shown in Exhibit V-16.

James River Bridge (June sample)
Rocklanding Shoal (June sample)
Fort Eustis (August sample)
Hog Island (June sample)
West of Swann Point (June and August samples)
Brandon (August sample)
Windmill Point (June sample)
Herring Creek (August sample)
Jordan Point (June sample)
Bailey Bay (June sample)
City Point (June sample)

The first six stations were located in the saline portion of the river, while the remainder were located in the fresh-water portion. Stations were located close together at Bailey Bay to give a concise view of Kepone near the source area at Hopewell. Sampling occurred during a 20-year low flow period of the James River.

The sampling conducted in the field was directed to: meteorological and hydrological information; channel and flow characteristics; physical and chemical characteristics of suspended load and bed sediments; and water quality characteristics. Kepone analyses were conducted on water, suspended load and bottom sediment samples.

Meteorological and hydrological data included wind velocity, direction, and wave height, including wave period and direction at

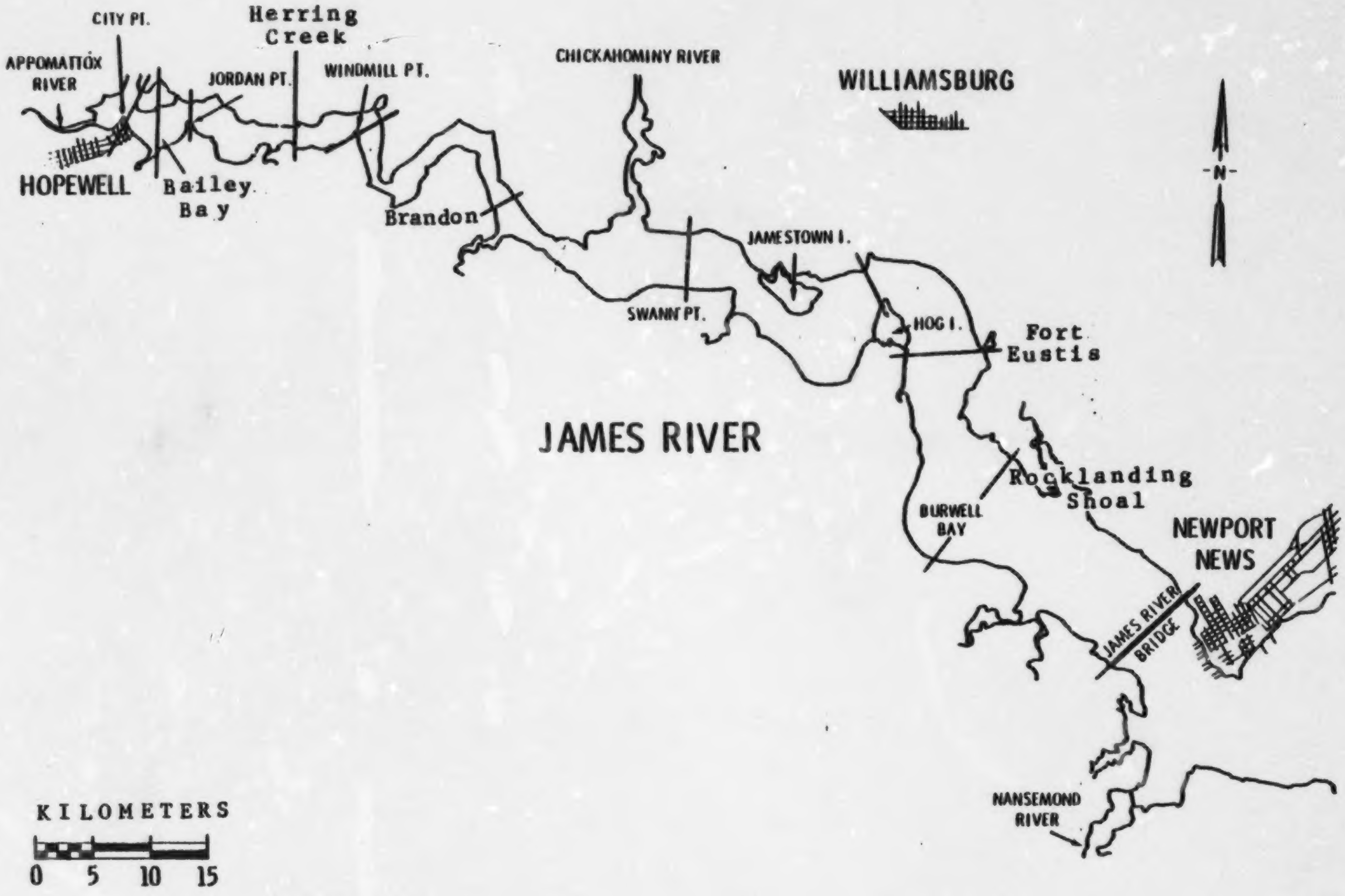

CITY PT.
Herring Creek
APPOMATTOX RIVER
JORDAN PT.
WINDMILL PT.
CHICKAHOMINY RIVER
WILLIAMSBURG
N
HOPEWELL
Bailey Bay
Brandon
JAMESTOWN I.
SWANN PT.
HOG I.
Fort Eustis
JAMES RIVER
Rocklanding Shoal
BURWELL BAY
NEWPORT NEWS
JAMES RIVER BRIDGE
NANSEMOND RIVER
KILOMETERS
0
5
10
15

Exhibit V-16 Tidal James River

each station. Wave height, direction, and period at each station were estimated from visual observations. Channel and flow characteristics included a bathymetric profile of each transect, tidal stage measurements, continuous current velocity/direction measurements at the mid-channel station, and current velocity measurements at each sampling depth at each station. Bathymetric profiles were taken at each cross section using continuous recording fathometers. Continuous current velocity/direction measurements were recorded and tidal stage measurements were also taken.

Water quality parameters measured at each station and depth included water temperature, dissolved oxygen, pH, and conductivity. Temperature measurements were taken by a readout module, and dissolved oxygen measurements were obtained using the modified Winkler titration method. Conductivity and pH measurements were performed on-board with a conductivity bridge and pH meter.

Two types of suspended sediment data were obtained. A 1-liter water sample was obtained from the Van Dorn water sampler for each depth for laboratory analysis of suspended sediment load. A continuous 76 liter (20 gal) water sample was obtained using a water pump at each station under each flow condition at a depth of 1.5 meters (5 ft) above the bed. These samples were stored in 19 liter (5 gal) containers and were decanted and centrifuged at a later date (2 weeks). The solids and supernatant water were analyzed in the laboratory for Kepone. Total suspended solids were measured using filtration. Details of the analytical procedure employed can be found in Appendix A.

Bathymetry

The tidal James River averages about 6.3 km (4 mi) wide in the more saline portion and 1.6 km (1 mi) or less in the upper freshwater tidal portion. The James River can be divided into the main flow channel of 6.1 meters (20 ft) or greater depth, channel margins of 3 to 6 meters (10 to 20 ft) depth, and subtidal flats of less than 3 meters (less than 10 ft) depth. In the lower or saline portion of the James River, the subtidal flats encompass to 90 percent of the bottom surface area. In the upper or nonsaline portion of the tidal James River, the subtidal flats seldom account for over 50 percent of the bottom surface area. Exhibit V-17 shows two of the transects across the James River at Bailey Bay and City Point.

Flow Characteristics

Flow characteristics in the tidal James River are primarily a function of tidal currents, freshwater discharge and wind-generated currents. During the June 25-28 sampling program, the freshwater discharge was very low and the wind velocity seldom exceeded 5 knots. Therefore, during this time period tidal generated currents were the

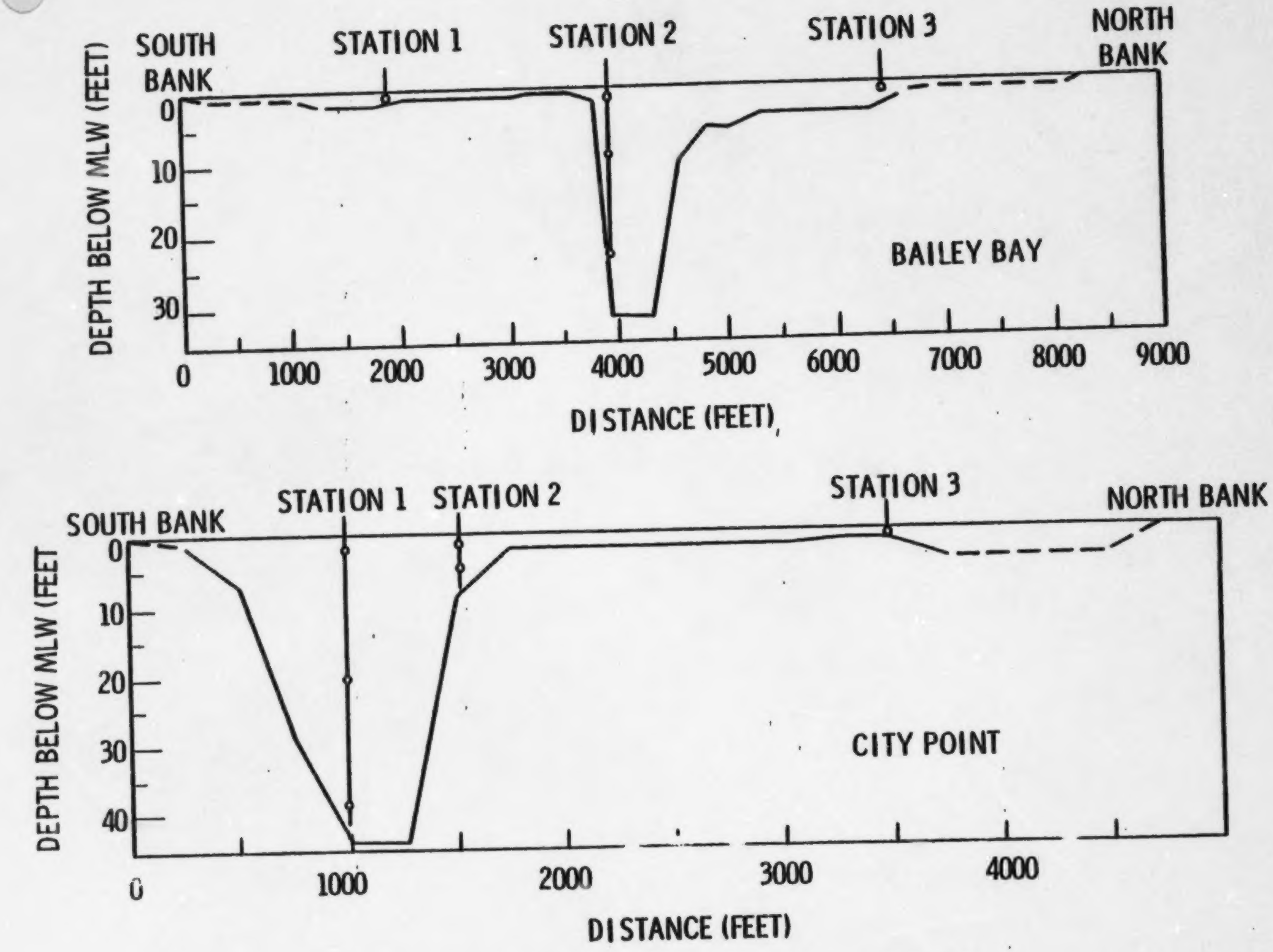


Exhibit V-17 Bathymetry at Bailey Bay and City Point

principal factor of water movement. Mid-channel current velocities differed only slightly from transect to transect, varying to slightly over 1 knot at maximum flood and ebb flow. The largest variations occurred in the lateral and vertical dimensions. Generally, current velocities decreased with depth and were greatest in the deep water flow channel, decreasing towards the tidal flats. During the sampling program on June 25-28, the flood currents were generally of greater magnitude and of longer duration than predicted, whereas the ebb currents were of lesser magnitude and of shorter duration than predicted. This deviation from the predicted currents is probably due to the extremely low freshwater discharge during the sampling program. Exhibit V-18 shows a comparison of predicted currents, continuous current records and depth-averaged instantaneous current velocity measurements at Rocklanding Shoal.

Conductivity

The largest variation of conductivity occurred in the longitudinal direction, varying from a maximum of 1,260 umhos at the James River Bridge to a minimum of 225 umhos at City Point. No large conductivity gradients were observed during the sampling program, either in the longitudinal or vertical directions. This absence of a large gradient in these two directions indicates the lack of a turbidity maximum (null zone area where fresh and saline waters intermix) and is due to the very low freshwater discharge during the June 25-28 sampling

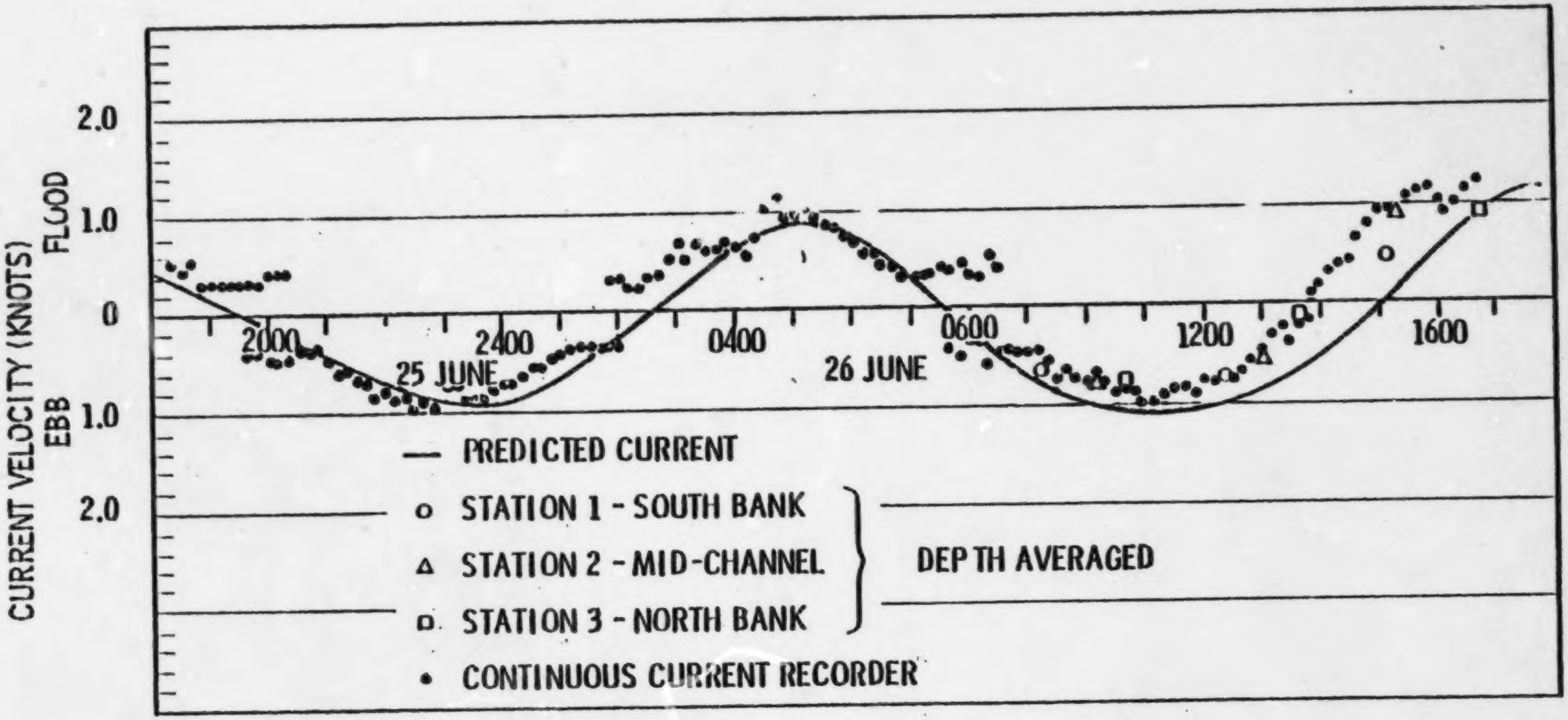


Exhibit V-18 Rocklanding Shoal

program. The average freshwater discharge of the James River at Carterville, Virginia is 200,000 l/sec (7,000 ft^3/sec). On June 25-28, the average discharge was 51,000 l/sec (1,800 ft^3/sec). Exhibit V-19 shows the average conductivity along the length of the James River as a function of tidal stage.

pH

The greatest variations of pH in the James River water during the June 25-28 sampling program occurred in the longitudinal direction, where it decreased in the upstream direction until the vicinity of Hopewell, where the pH increased dramatically. Exhibit V-20 illustrates the longitudinal changes during flood, ebb, and slack flows. During flood, the depth-averaged pH at the James River Bridge was 7.7 and decreased to 7.0 at Windmill Point. The pH then increased slightly to 7.1 at Jordan Point and Bailey Bay. At City Point, the pH increased dramatically to 8.5. The highest pH during the June 25-28 sampling program was observed at the mouth of Bailey Creek during ebb with a measurement of 11.0. The high pH values found in Bailey Bay between Jordan and City Points probably can be attributed to the high pH of industrial discharges into Bailey Creek and Bailey Bay.

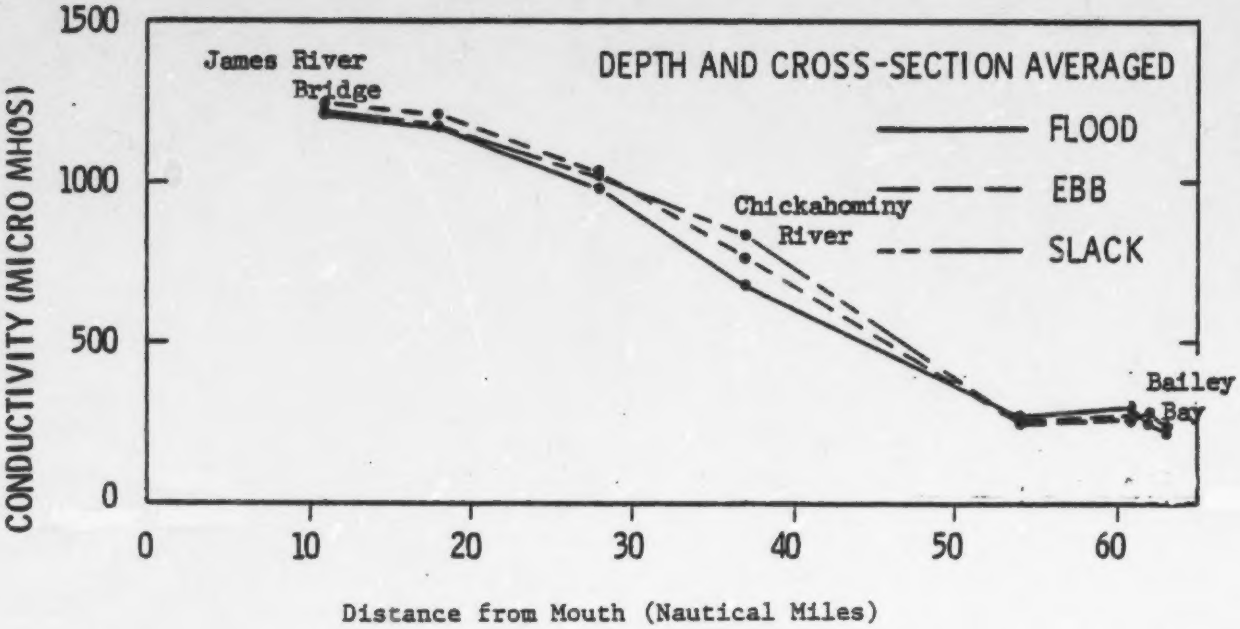


Exhibit V-19 Average Conductivity as a Function of Tidal Stage

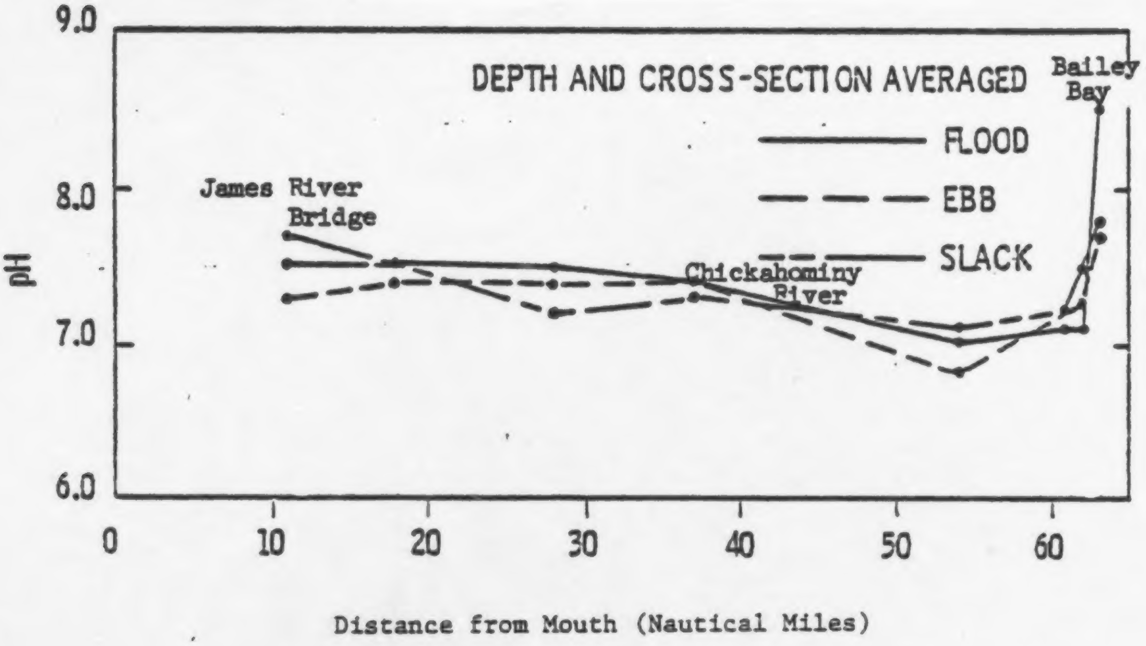


Exhibit V-20 Longitudinal Variation of pH

Dissolved Oxygen

During the June 25-28 sampling program, dissolved oxygen (DO) ranged from a value of 0 mg/l (ppm) in Bailey Creek to 9.2 mg/l (ppm) in the north side of the channel opposite Jordan Point. Dissolved oxygen levels remained unchanged or increased slightly in the upstream direction from James River to west of Swann Point, where the average concentrations were between 6 mg/l (ppm) and 7 mg/l (ppm) (Exhibit V-21). From Swann Point to Jordan Point, dissolved oxygen levels decreased dramatically during flood and slack waters to concentrations between 2 mg/l and 3 mg/l (ppm). Dissolved oxygen levels increased to concentrations of 4 mg/l to 6 mg/l (ppm) between Jordan Point and City Point. The tidal phase variations of dissolved oxygen were small in the lower tidal James River but were large in the upper portion, varying from 2.5 mg/l (ppm) during flood stage to 5.5 mg/l (ppm) during ebb stage at Jordan Point.

Temperature

The water temperature during the June 25-28 sampling program ranged from 26.8 to 32 degrees C. Water temperatures in Bailey Creek generally exceeded those in the James, ranging from 32 to 35.5 degrees C. Water temperature closely followed the daily temperature pattern with the lowest temperatures in the morning and the highest in the late afternoon. Slight vertical gradients of

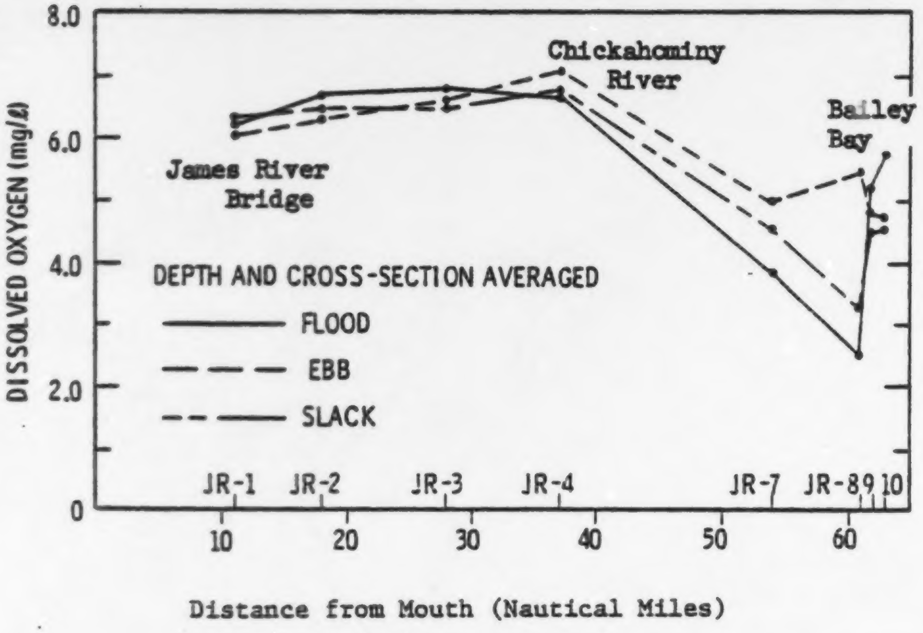


Exhibit V-21 Variation of Dissolved Oxygen with Tidal Stage

approximately 1 degree C were observed in the deeper areas. The shallow subtidal flats tended to have a greater range in water temperatures than did the deeper areas of the river.

Suspended Sediment

The suspended sediment load of the tidal James River during the June 25-28 sampling program was quite variable in the longitudinal, lateral, and vertical dimensions. Suspended sediment loads were observed to be as high as 98.6 mg/l (ppm) and as low as 11.1 mg/l (ppm). Generally, as shown in Exhibit V-22, high suspended solids levels were found in the lower portion of the river between Newport News and Hog Island, and in the upper portion around Hopewell. The levels were generally lower in the stretch of river between Hog Island and Windmill Point.

Kepone

Longitudinal variations of Kepone associated with suspended sediment during the June 25-28 sampling program are shown in Exhibit V-23. Kepone levels were found to generally decrease in the downstream direction from the source area near Hopewell. The highest Kepone levels were found in Bailey Creek suspended sediment with levels exceeding 1.0 ug/g (ppm). The lowest Kepone levels were found at the furthest downstream sampling location at the James River Bridge

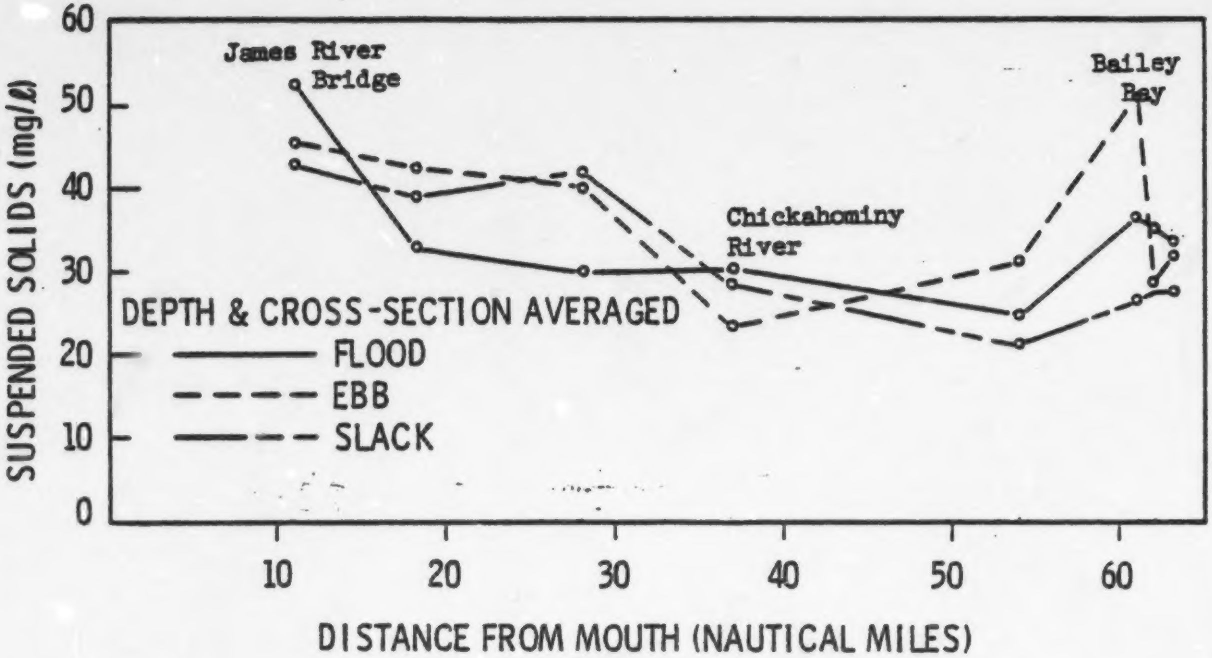


Exhibit V-22 Longitudinal Variation of Suspended Solids

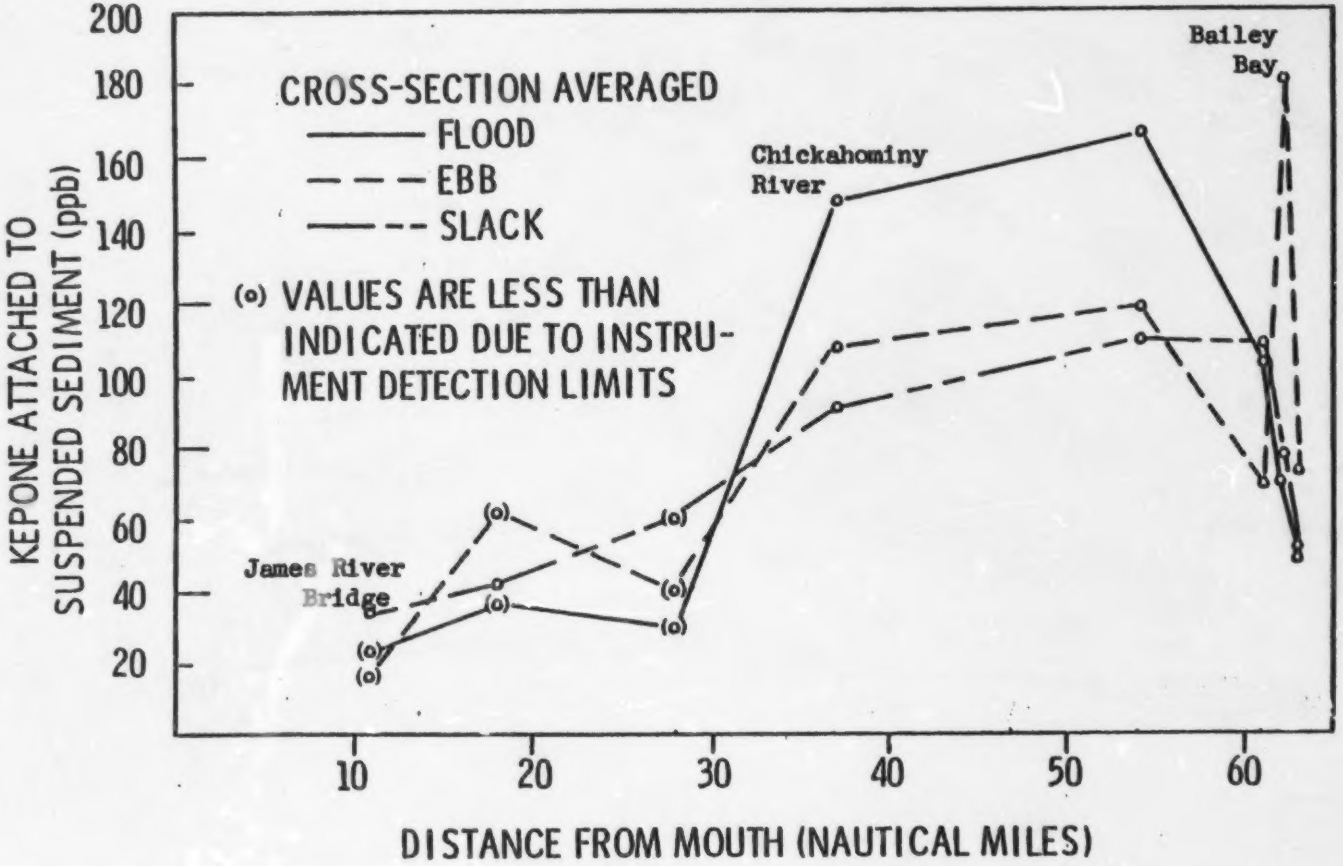


Exhibit V-23 Longitudinal Variation of Kepone Attached to Suspended Sediment

with levels less than 11 ng/g (ppb). The largest longitudinal decrease in concentrations occurred between Hog Island and just west of Swann Point. Large lateral variations in Kepone levels attached to the suspended sediment were observed. These lateral variations are shown in Exhibit V-24. The largest lateral variations occurred between Hog Island and Jordan Point.

Exhibit V-25 shows Kepone distribution with depth of the James River bottom sediments and by sediment size. The bulk of the Kepone is associated with the larger-sized sediment particles which are greater than 62 microns. Exhibit V-26 shows the Kepone concentrations found by Battelle in composite sediment samples for all their sampling stations from Newport News to Hopewell. Battelle's estimates for the amounts of Kepone found in various sections of the James River is shown in Exhibit V-27, but should be considered only an approximation.

Over the past two years, comprehensive sediment sampling was undertaken by the Virginia State Water Control Board (SWCB) and the Virginia Institute of Marine Science (VIMS) to determine the amount of Kepone in all areas of the tidal James River. The resulting Kepone distribution pattern compiled by the SWCB from their data is shown in Exhibits V-28 to V-30. Independent estimates of the total current Kepone deposits in the James River sediments have been made by Battelle (Appendix A) and by VIMS (Bender, 1977a). The two estimates compare favorably. Battelle estimated an average of 9,600 kg

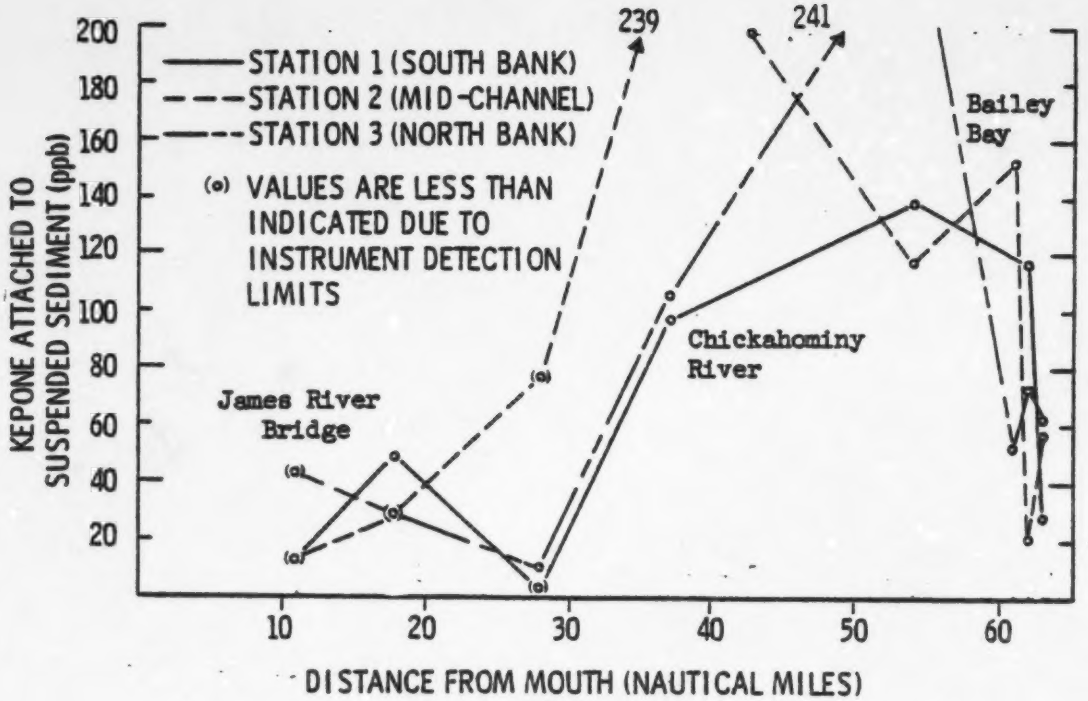


Exhibit V-24 Lateral Variation of Kepone Attached to Suspended Sediment During Flood

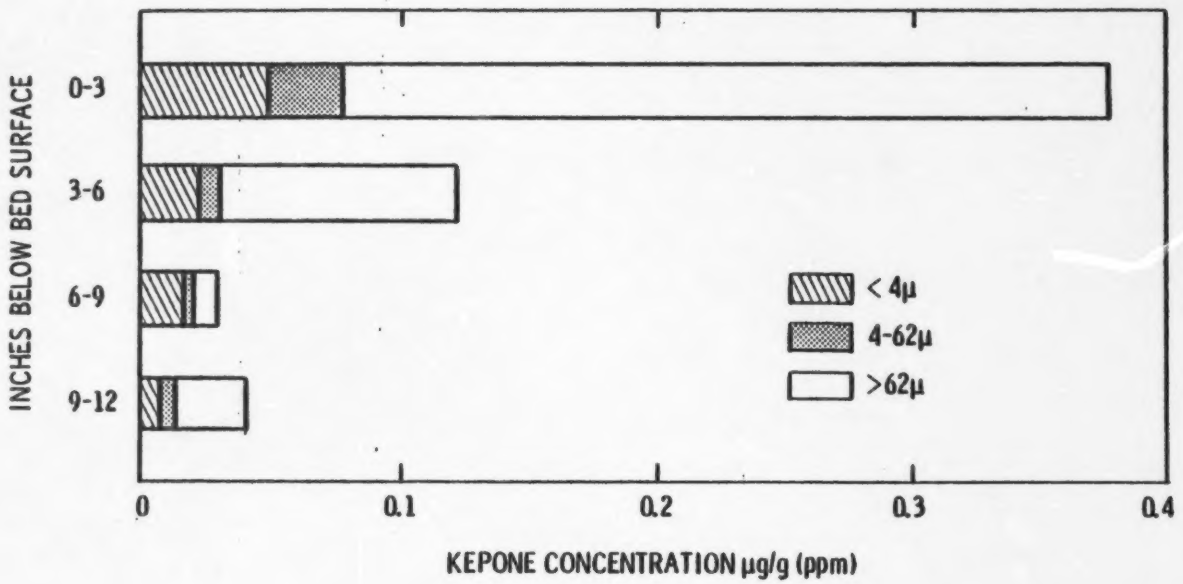


Exhibit V-25 Depth Distribution of Kepone by Sediment Size Fraction - West of Swann Point

Exhibit V-26 KEPONE IN BED SEDIMENTS

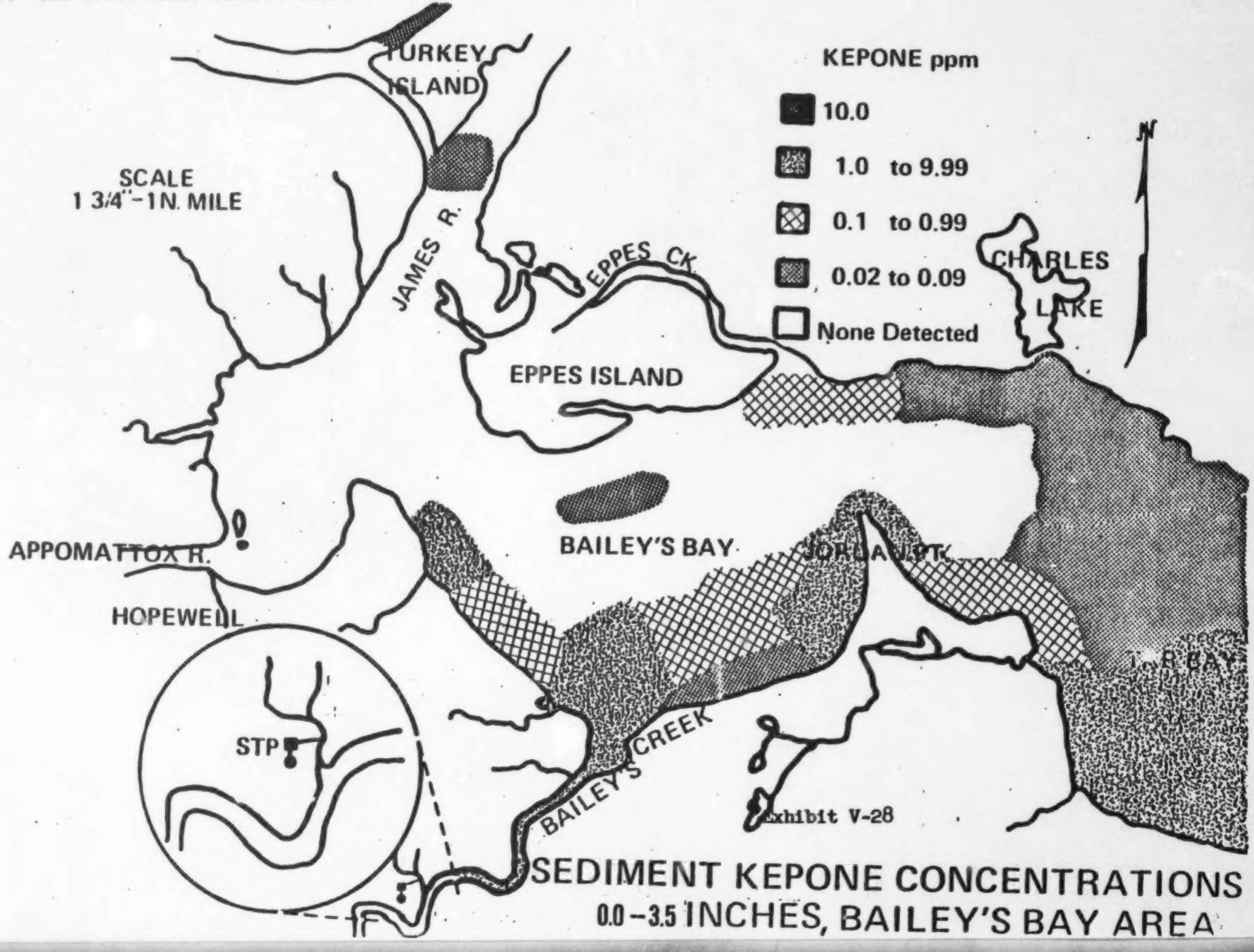
Cross-Section	Station	Composite Depth (in.)	Kepone (µg/g) (ppm)
James River Br.	1	0-12	<0.002
"	2	0-12	0.003
"	3	0-12	<0.002
Rocklanding Shoal	1	0-12	<0.002
"	2	0-12	<0.005
"	3	0-4	<0.001
Hog Island	1	0-12	<0.001
"	3	0-5	<0.003
West of Swann Pt.	1	0-10	<0.002
"	2	0-12	<0.002
"	3	0-12	<0.002
Windmill Pt.	1	0-12	0.044
"	2	0-1	0.170
"	3	0-12	0.032
Jordan Point	1	0-12	0.422
"	2	0-12	<0.001
"	3	0-12	0.005
Bailey Bay	1	0-6	0.009
"	3	0-12	<0.003
City Point	1	0-12	0.006
"	2	0-12	<0.003
"	3	0-12	<0.003

Exhibit V-27

BASIS FOR ESTIMATE OF KEPONE DEPOSITS IN JAMES RIVER SEDIMENTS

	Bailey Bay	Jordan Point to Turkey Island	Jamestown to Jordan Point	Newport News to Jamestown Island	Hampton Roads	Total
Area	800 acres	3.3 mi^2	44.9 mi^2	132.7 mi^2	60.9 mi^2	243.1 mi^2
Mean concentration µg/g-ppm	0.91	0.07	0.15	0.08	0.023	
Mean + one standard deviation µg/g-ppm	3.31	0.21	0.28	0.15	0.0375	
Volume (ft^3) assumes 1 ft depth	3.5×10^7	9.2×10^7	1.25×10^9	3.7×10^9	1.7×10^9	6.8×10^9
Mass of dry sediments (lb)(assumes 70 lb/ft^3)	1.3×10^9	3.48×10^9	4.7×10^{10}	1.4×10^{11}	6.4×10^{10}	2.5×10^{11}
Mean total Kepone (kg)	537	110	3,204	5,091	670	9,612
(lb)	1,183	243	7,050	11,200	1,472	21,148
Maximum total Kepone (kg)	1,956	332	6,000	9,545	1,091	18,924
[mean + std. deviation](lb)	4,303	730	13,160	21,000	2,400	41,593
Number of sample sites	25	9	66	66	39	205
Number of points with <0.02 µg/g Kepone	3	3	5	13	21	45
Sampling density (points/mi^2)	20	2.7	1.5	0.5	0.64	

Assumes 12 in. depth at mean even though some samples were analyzed to depths less than 12 in. Since concentrations decline with depth, estimate here is conservative.


TURKEY ISLAND
SCALE
1 3/4"-1N. MILE
JAMES R.
EPPES CK.
EPPES ISLAND
CHARLES LAKE
N
KEPONE ppm
■ 10.0
▨ 1.0 to 9.99
▨ 0.1 to 0.99
▨ 0.02 to 0.09
☐ None Detected
BAILEY'S BAY
APPOMATTOX R.
HOPEWELL
STP
JORDAN PT.
BAILEY'S CREEK
R. BAY

Source: Va. State Water Control Board (1977-1978)

Exhibit V-28

SEDIMENT KEPONE CONCENTRATIONS
0.0 – 3.5 INCHES, BAILEY'S BAY AREA

Source: Va. State Water Control Board (1977-1978)

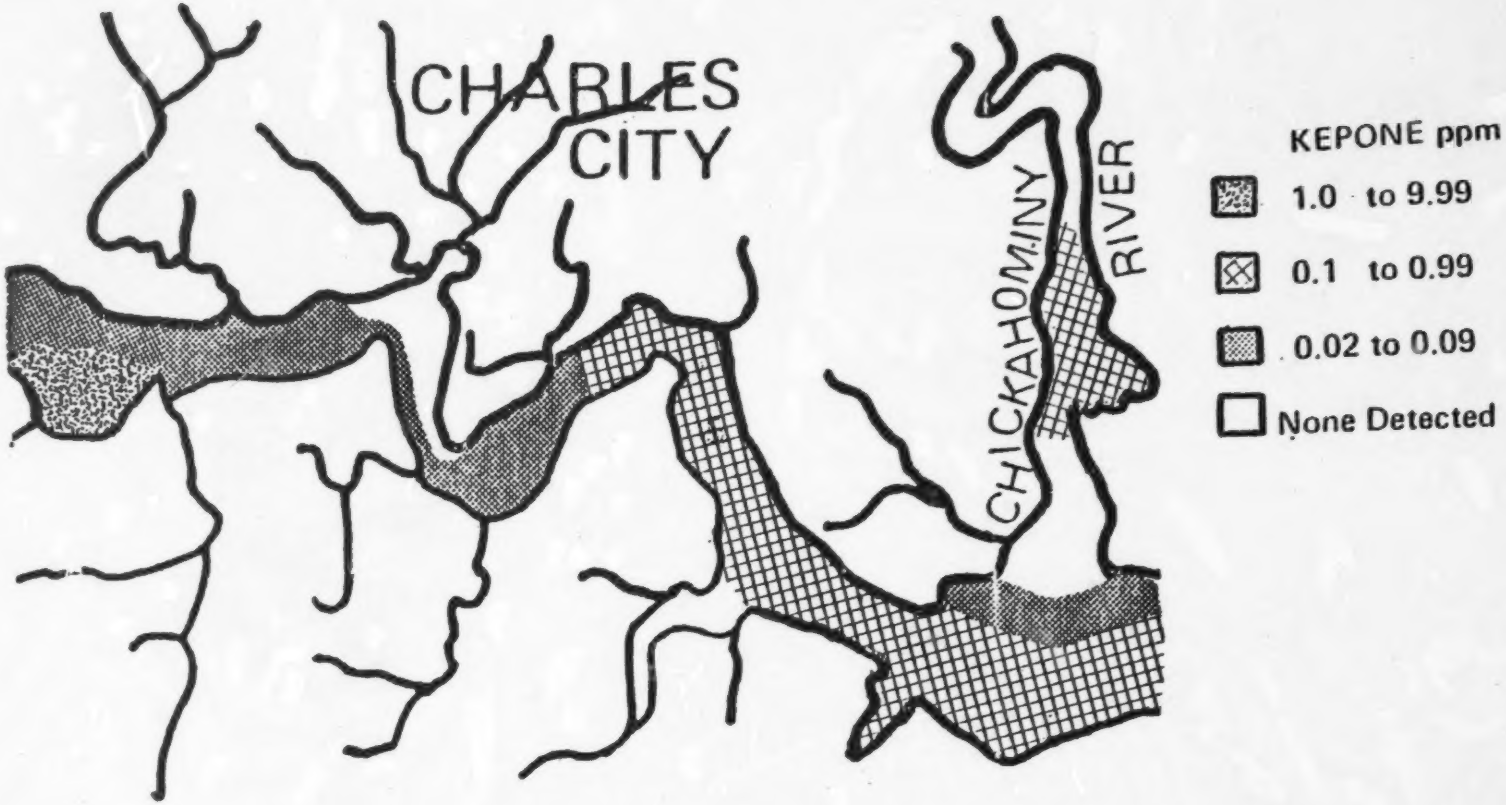

CHARLES CITY
CHICKAHOMINY RIVER
KEPONE ppm
1.0 to 9.99
0.1 to 0.99
0.02 to 0.09
None Detected

Exhibit V-29

SEDIMENT KEPONE CONCENTRATIONS
0.0 – 3.5 INCHES, TAR BAY TO CHICKAHOMINY RIVER

Source: Va. State Water Control Board (1977-1978)

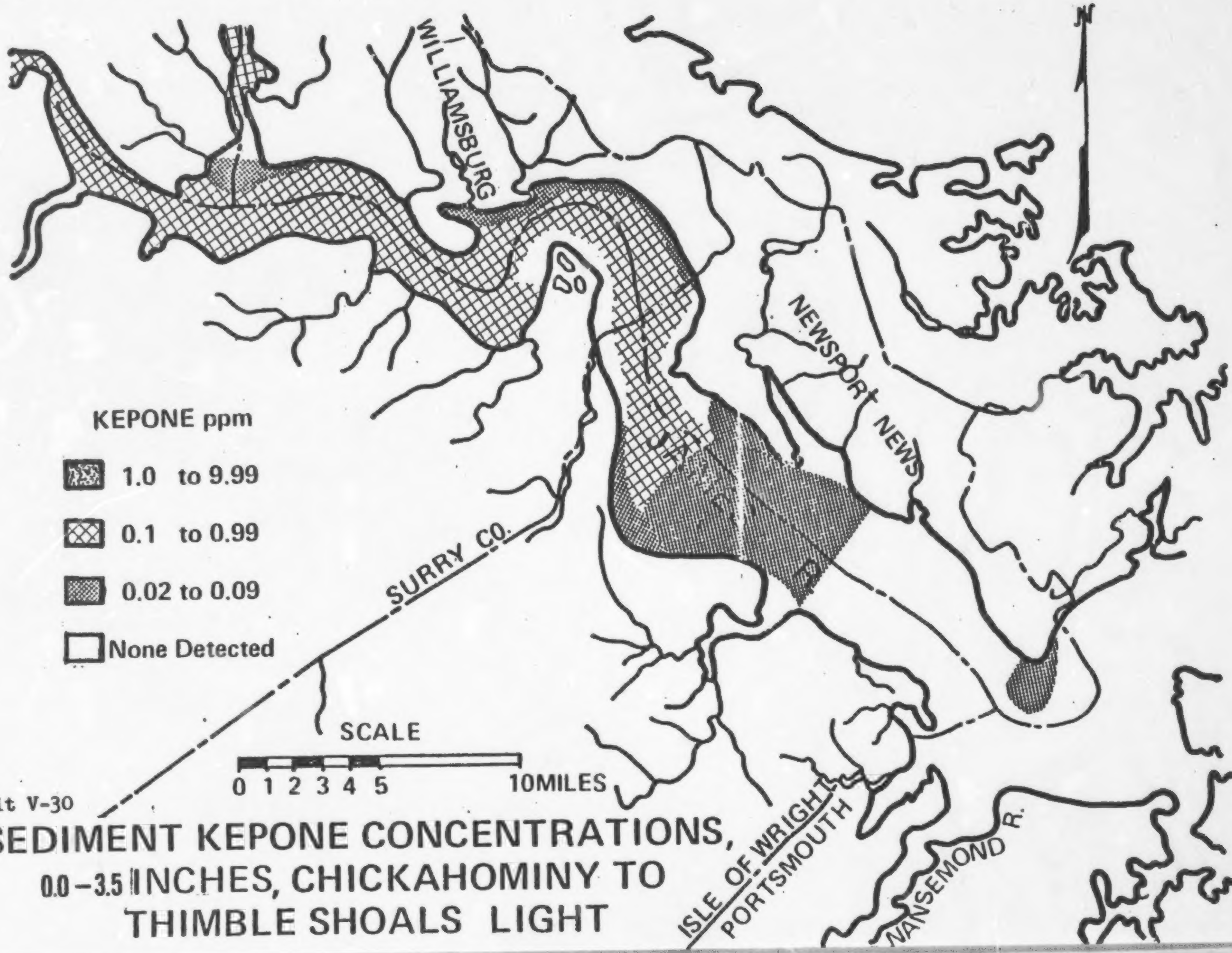

WILLIAMSBURG
NEWSPORT NEWS
SURRY CO.
ISLE OF WRIGHT
PORTSMOUTH
NANSEMOND R.
N
KEPONE ppm
▨ 1.0 to 9.99
▨ 0.1 to 0.99
▨ 0.02 to 0.09
☐ None Detected
SCALE
0 1 2 3 4 5 10MILES

Exhibit V-30

SEDIMENT KEPONE CONCENTRATIONS, 0.0 – 3.5 INCHES, CHICKAHOMINY TO THIMBLE SHOALS LIGHT

(21,000 lb) and a maximum of 19,000 kg (42,000 lb), while VIMS estimated 11,000 to 18,000 kg (25,000 to 40,000 lb). The majority of this Kepone lies in the sediments of the turbidity maximum zone.

Summary of Environmental Inventories

Summarized in Exhibit V-31 are Battelle's estimates from current data of the amount of Kepone residing in the James River and Hopewell area environment. Of approximately 25,000 pounds of Kepone identified in the James River and land areas excluding drummed material, less than 2,300 kg (5,000 lb) persist in the Hopewell/Bailey Bay region. A majority of the Kepone residuals have migrated into the James River, and currently are associated with the underlying sediment. The largest remaining terrestrial Kepone deposit is the estimated 1,400 kg (3,100 lb) in marsh sediment adjacent to the southeastern portion of the Hopewell landfill.

Exhibit V-31 ESTIMATE OF KEPONE RESIDUALS INCLUDING MATERIAL DRUMMED AT THE LIFE SCIENCE PRODUCTS PLANT AFTER CLOSURE (DECEMBER 1977)

Residing In	Estimated Quantity	
	kg	lb
Sewer system	23	50
Surface soil (1 in.)*	45–450	100–1,000
Kepone sludge lagoon	100	220
Bailey Bay sediments*	540–2,000	1,200–4,300
James River sediments*	9,000–17,000	20,000–38,000
Drums at Hopewell	9,400	20,700
Drums at Portsmouth	3,700	8,100
Landfill+	1,400	3,100
Pebbled Ammonium Nitrate plant site	100	220
Rounded total*	24,400-34,300	53,600-75,600

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* Low value reflects estimate extrapolated from mean concentrations; high value reflects estimates based on mean plus one standard deviation.

+ Includes identified deposits only.

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VI. BIOLOGICAL FATE, IMPACT, AND CLEAN-UP INDICES

ACUTE TOXICITY TO SALT-WATER ORGANISMS

Kepone was found by the EPA Gulf Breeze Environmental Research Laboratory (Appendix C) to be acutely toxic to algae, oysters, shrimps, and fishes. It was found not to be toxic to blue crabs at the levels tested (210 ug/l). Nine species of estuarine organisms, of which eight are known to exist in the James River, were investigated for acute toxicity. The organisms were: the unicellular algae, Chlorococcum sp., Dunaliella tertiolecta, Nitzchia sp., and Thalassiosira pseudonana; the grass shrimp (Palaemonetes pugio), blue crab (Callinectes sapidus), sheepshead minnow (Cyprinodon variegatus), and spot (Leiostomus xanthurus). The 96-hour LC50 varied widely. The most sensitive species tested was spot, which had an LC50 of 6.6 ug/l (ppb). The second-most sensitive species tested was the marine mysid, Mysidopsis bahia, which had an LC50 of 10.1 ug/l (ppb). This species is not found in the Chesapeake region, but other species of Mysidopsis and mysids inhabit northern Atlantic waters. The oyster larvae EC50 was reported at 69.5 ug/l (ppb). The sheepshead minnow had an LC50 of 70 ug/l (ppb), while the grass shrimp were more tolerant with an LC50 of 120.9 ug/l (ppb). Algal growth was reduced to 50 percent by concentrations of 350 to 600 ug/l (ppb) (Appendix C, No. 5 and 4).

In a comparison of six sediment types from around the United States, Swartz, et al. (1977) examined the toxicity of the settleable phase of dredged material to marine benthic organisms. They found that mean survival after 10 days' exposure to Bailey Creek sediments was significantly less than controls. No attempt was made to determine which toxicant(s) may have caused the mortalities.

CHRONIC TOXICITY TO SALT-WATER ORGANISMS

Kepone also was found to cause pronounced chronic toxicity, reproductive, and teratogenic effects in life-cycle tests with estuarine mysids. Life-cycle toxicity tests were conducted using survival, reproduction, and growth of mysids (Mysidopsis bahia) as criteria for effects of toxicity of Kepone (Appendix C, No. 3). The 19-day (life-cycle) LC50 was 1.4 ug/l (ppb) at 25 to 28 degrees C and 10 to 20 ppth salinity. The duration of the test allowed production of several broods. The average number of young per female at 20 days was 15.3 in the controls, and 8.9 in 0.39 ug/l (ppb) Kepone. There were significant differences between controls and the 0.39 ug/l (ppb) concentration indicating that the average number of young produced per female had been reduced by the presence of Kepone.

In preliminary tests, growth of some mysid individuals in higher concentrations of Kepone appeared to be less than control mysids. To evaluate this effect, two separate 14-day tests were begun by exposing

24-hour-old juveniles to Kepone and concluded by measuring their total body lengths. Female mysids exposed to 0.072 ug/l (ppb) Kepone grew less than the control mysids. This effect was consistent with apparent effects on reproductive success (fewer juveniles per female). Sublethal effects observed after prolonged exposure to Kepone were: (1) delay in the formation of brood pouches; (2) delay in the release of young; (3) fewer young produced per female, and (4) reduced growth. In nature, the loss of mysids due to the direct toxic effects of pollutants or the indirect effects on their growth or population size could affect the food supply of many fishes (Appendix C, No. 3).

The chronic effect of Kepone on sheepshead minnow growth and survival of embryo, fry, and juveniles was investigated by Hansen, et al. (Appendix C, No. 6). Adult minnows were held in Kepone concentrations ranging from 0.05 to 24.0 ug/l (ppb) for 29 days. All of the fish in the higher two concentrations (7.8 and 24 ppb) died. Survivors of the 28-day bioassay spawned and the progeny were observed for survival, growth, hatching and development in a 36-day exposure to six Kepone concentrations from 0.08 to 33.0 ug/l (ppb). A significant portion of the embryos, produced by adults previously exposed to Kepone (1.9 ppb) died during embryonic development even when held in Kepone-free water. Kepone, which was bioconcentrated by adults (5,200 X), was passed to embryos and was very slow to depurate. Forty-six percent of the Kepone in the eggs was still found in the fry 36 days after hatching. Fry exposed to 0.08 ug/l (ppb) were stunted.

SYMPTOMS OF EXPOSURE

Symptoms of poisoning in fish during exposure were darkening of the posterior of the body, hemorrhaging near the brain, fin rot, loss of swimming coordination, cessation of feeding, and scoliosis. Onset of these symptoms was related to concentration and length of exposure.

KEPONE BIOCONCENTRATION FROM WATER

Kepone was bioconcentrated from water by algae, oysters, mysid shrimp, grass shrimp, sheepshead minnows, and spot in all concentrations tested, and all species showed Kepone at equilibrium levels in tissues within 8 to 17 days after exposure to Kepone began (Appendix C, No. 9). Bioconcentration factors for Kepone in these species ranged from 2,300 to 13,500 in long-term (96-hour) flow-through bioassays. Kepone bioconcentrated in oysters to approximately 10,000 times the concentration in water within 19 days. Mysid shrimp (Mysidopsis bahia) bioconcentrated Kepone to 13,000 times the amount measured in the exposure water. The grass shrimp (Palaemonetes pugio) also has a high bioconcentration factor for Kepone, and like other decapod crustaceans is one of the least sensitive species to acute exposures (Appendix C, No. 5). Grass shrimp bioconcentrated Kepone to 11,000 times the concentration in water. Sheepshead minnows bioconcentrated Kepone 7,200 times the concentration in water, and spot bioconcentration factors were approximately 3,000. Twenty-two percent of Kepone accumulated in edible fillets of spot - one of the largest quantities of Kepone in total weight. Although the greatest body concentrations of Kepone on a unit basis were in the brain, liver and gill tissues, the relatively large mass of muscle and offal tissues accounted for their having the high Kepone quantities (Appendix C, No. 9). A summary chart on bioconcentration and bioaccumulation values is shown in Exhibit VI-1.

Uptake by Mollusks Exposed to Suspended Sediment

The Virginia Institute of Marine Science completed eight Kepone-uptake experiments with the oyster (*Crassostrea virginica*) five experiments with the clam (*Rangia cuneata*) and one experiment with the clam (*Macoma balthica*) which involved exposure of the animals to Kepone-contaminated sediments in suspension. The oysters exhibited high Kepone concentrations in their meats when they were exposed to mean hourly concentrations of Kepone at 0.153 ug/g (ppm) in the suspended sediments (Exhibit VI-2). The bivalves *Crassostrea virginica*, *Rangia cuneata*, and *Macoma balthica* concentrated Kepone from suspended sediments by factors ranging between 1,000 and 3,000 over that in the water (Appendix C, No. 18).

In another experiment, the *Rangia* and the oyster were buried in a bed of Kepone-contaminated sediments with uncontaminated river water flowing over them. The shellfish generally accumulated Kepone and

Exhibit VI-1
Chronic Effects, Bioconcentration and Bioaccumulation of Kepone

Species	Exposure	Result	Tissue Concentration	Bioconcentration Factor	Bioaccumulation Factor	Reference
Chlorococcum sp.	100 ppb, 24 hr	EC_{50}(growth) = 0.35 ppm	80.0 ppm	800		Walsh et al., 1977
Dunaliella tertiolecta	3 times in 7 day	= 0.58	23.0	230		
Nitzshia sp.		= 0.60	41.0	410		
Thalossiosira psuedonana		= 0.60	52.0	520		
Grass shrimp Paleomonetes pugio	12-121 ppb 96 hr	LC_{50}=120ug/l	5.1-94.0 ppm	690		Schimmel and Wilson, 1977
Blue Crab Callinectes sapides	110-210	LC_{50}=>210ug/l	0.85-1.3	8.1		
Sheepshead minnow Cyprinodon variegatus	7.1-78.5 96 hr	LC_{50}=70ug/l	11.2-118.4	1,548		
Spot Leiostomus xanthurus	1.5-15.9 96 hr	LC_{50}=6.6ug/l	1.7-16.8	1,221		
Oyster Crassostrea virginica	0.03-0.39 ppb 28 day		0.29-3.6 ppm	9,354-9,278	Algae → Oyster = 2.1 Water → Algae → Oyster = 0.007	Bahner et al., 1977
Mysid Mysidopsis bahia	0.026-0.41 21 day		0.19-6.3	5,962-13,473	Brine shrimp → mysids = 0.53	
Grass shrimp Paleomonetes pugio	0.023-0.40 28 day		0.09-4.57	5,127-11,425		
Sheepshead minnow Cyprinodon variegatus	0.05 28 day		0.37	7,115		
Spot Leiostomus xanthurus	0.029-0.40 30 day		0.06-0.99	3,217-2,340	Mysid → Spot = 0.85 Brine shrimp → mysid → Spot = 10.5	
Sheepshead minnow Cyprinodon variegatas						
Adults	0.05-24.0 ppb 28 day	LC_{50} = 1.3 ppb	0.25-12 ppm	5,200		Hansen et al., 1977
Juveniles	0.08-33 ppb 36 day	LC_{50} = 6.7 ppb	0.13-22 ppm	7,200		

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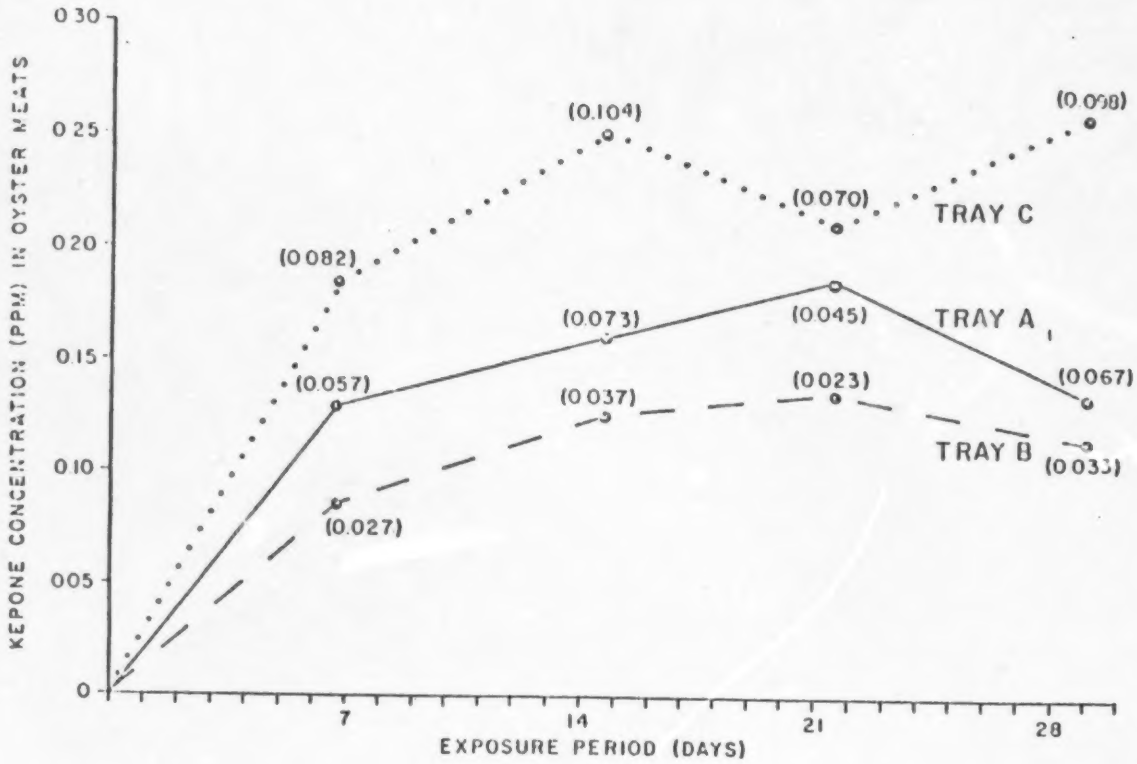


Exhibit VI-2 Mean concentration of Kepone in meats of oysters exposed to contaminated sediments in suspension. First series of experiments, 24 Feb.-27 March 1977. Figures in parentheses are mean hourly concentration of Kepone in sediments for weekly period ending at that point.

(Appendix C, No. 18)

then gradually lost most or all of it. Oysters averaged 0.037 ug/g (ppm) after a week of burial, but then lost Kepone to non-detectable levels. Rangia followed a similar pattern to that of the oyster (Appendix C, No. 18).

At the same time that oysters were accumulating Kepone in their tissues to levels greater than that of the water, they were also redepositing high concentrations of the chemical in the form of feces and pseudofeces. The bioconcentration factors for oyster feces ranged from 11,000 to 55,000. In pseudofeces, the range was between 3,000 and 20,000. The concentration in feces was always higher than that in pseudofeces, but the magnitude of the difference varied. This redeposition of feces and pseudofeces was in the form of material less likely to be resuspended because of its nature as an aggregate (Appendix C, No. 18).

Depuration from Exposed Animals

Kepone depuration was most rapid in the oysters with Kepone reaching nondetectable levels within 7 to 20 days; other organisms were much slower, particularly grass shrimp and fish. Kepone concentrations remained at 50 to 70 percent of the peak value in the flesh for 24 to 28 days after initiation of depuration in these species (Appendix C, No. 9).

Field studies included collecting Kepone-laden oysters from the James River and moving them to uncontaminated areas (Bender, 1977). These transplanted oysters were sampled over time to determine the effects of seasonal changes on the depuration rate. As might be expected, the oysters depurated more slowly in the winter when metabolic activity levels were depressed. The biological half-life of Kepone in oysters in the summer is approximately one week, while in the winter 40 days is required before there is a measurable decline in the residue levels.

KEPONE BIOACCUMULATION FROM FOOD

Bahner, *et al*., and Schimmel, *et al*., (Appendix C, No. 9 and 14) investigated the transfer of Kepone through a series of food chain experiments representative of various trophic (energy) levels from plankton to fish. Not all of the species were indigenous to the James River ecosystem, but they did serve as models.

Three study routes were examined:

1. Water--------------> Algae--------------> Oyster
2. Water--------------> Oyster-------------> Blue Crab
3. Water--------------> Brine shrimp-------> Mysid shrimp---> Spot

In a 14-day experiment, oysters bioaccumulated Kepone to 0.21 ug/g (ppm) when fed the single-celled alga (Chlorococcum sp.) containing an average of 34 ug/g (ppm) of Kepone. Kepone was not detectable (less than 0.02 ug/g) 10 days after the oyster (Crassostrea virginica) received no contaminated food. The quantity of Kepone transferred from these algae to oysters was limited, probably due to rapid depuration of the chemical from the oysters. Most of the Kepone was depurated from oysters within 96 hours. Blue crabs, fed oysters contaminated with 0.15 or 0.25 ug/g (ppm) Kepone, accumulated the insecticide readily in their muscle and whole-body tissues in 28 days, but after an additional 29 days in a Kepone-free environment, no depuration of the compound was evident. Both concentrations in food increased mortality in the crabs (Appendix C, No. 14).

Brine shrimp (Artemia salina) served as "plankton" and were preyed upon by mysid shrimp (Mysidopsis bahia) which in turn were fed to spot (Leiostomus xanthurus). Kepone concentration in spot, which consumed mysids for 30 days, were slightly less than that of mysids, but the uptake of Kepone exceeded the fishes' depuration. The bioaccumulation factor from mysids to spot was estimated at greater than 0.85, while the bioaccumulation factor for the entire food chain was greater than 10.5 (Appendix C, No. 9).

KEPONE BIOAVAILABILITY FROM SEDIMENT

Two benthic, burrowing species, lugworms (*Arenicola cristata*) and fiddler crabs (*Uca pugilator*), were exposed to James River estuarine sediments containing Kepone at approximately 0.25 ug/g (ppm). Both species had attained whole-body residues of 0.25-0.3 ug/g (ppm) within 10 days of exposure. No lugworms remained alive after 21 days exposure to the James River sediments. Depuration of Kepone from fiddler crabs placed on uncontaminated sediments was minimal after 35 days (Bahner, *et al.*, in preparation).

COMPARATIVE ROUTES OF UPTAKE

Comparisons of Kepone residues in various animals to determine the probable modes of entry of Kepone into organisms have been made (Appendix C, No. 9). Kepone accumulation can be attained via water, sediment, or food as indicated by Exhibit VI-3. In most cases, uptake from water directly impacts each animal, but uptake from food and sediment can be of great importance when effects on the entire James River estuary are considered. Specifically, blue crabs gain most of their Kepone by eating animal tissues, rather than uptake from water,

Exhibit VI-3

Comparison of Kepone residues in eight species of estuarine organisms exposed to low concentration of Kepone in water, food, and sediments in flow-through experiments (Gulf Breeze,1977)

Species	Probable Mode of Uptake
Oyster	Water
Polychaete worms	Sediment & food
Mysids	—
Grass Shrimp	Food
Fiddler crab	Sediment & Food
Blue crab	Food
Sheepshead minnow	Water, food
Spot	Food

while benthic organisms accumulate considerable quantities of Kepone from sediment ingestion and supply these amounts to their predators for food-chain transfer.

Indirect Impacts on Fisheries

Stomachs of flounders from Chesapeake Bay contained an average of twenty mysids (Stickney, et al., 1974), while mysids comprised up to 14 percent of the diet of striped bass from the York and Rappahannock Rivers. Mysids were conspicuously absent in the gut analyses of James River striped bass, indicating this particular food chain has been severely altered. A partial food web for selected James River species is shown in Exhibit VI-4. However, no evidence is available to directly link Kepone as the causative agent in this situation.

The uptake and slow depuration of Kepone by blue crabs may explain why relatively high Kepone residues are found in crabs from the James River, Virginia. Bender, et al., (1977) reported that average Kepone concentrations in estuarine vertebrates and invertebrates ranged from 0.09 to 2.0 ug/g (ppm) in the James River. Many, if not all of these species, are included in the diet of the blue crab. It is reasonable to conclude that Kepone residues will remain in the blue crab tissues as long as detectable concentrations remain in the crab's food (Appendix C, No. 14).

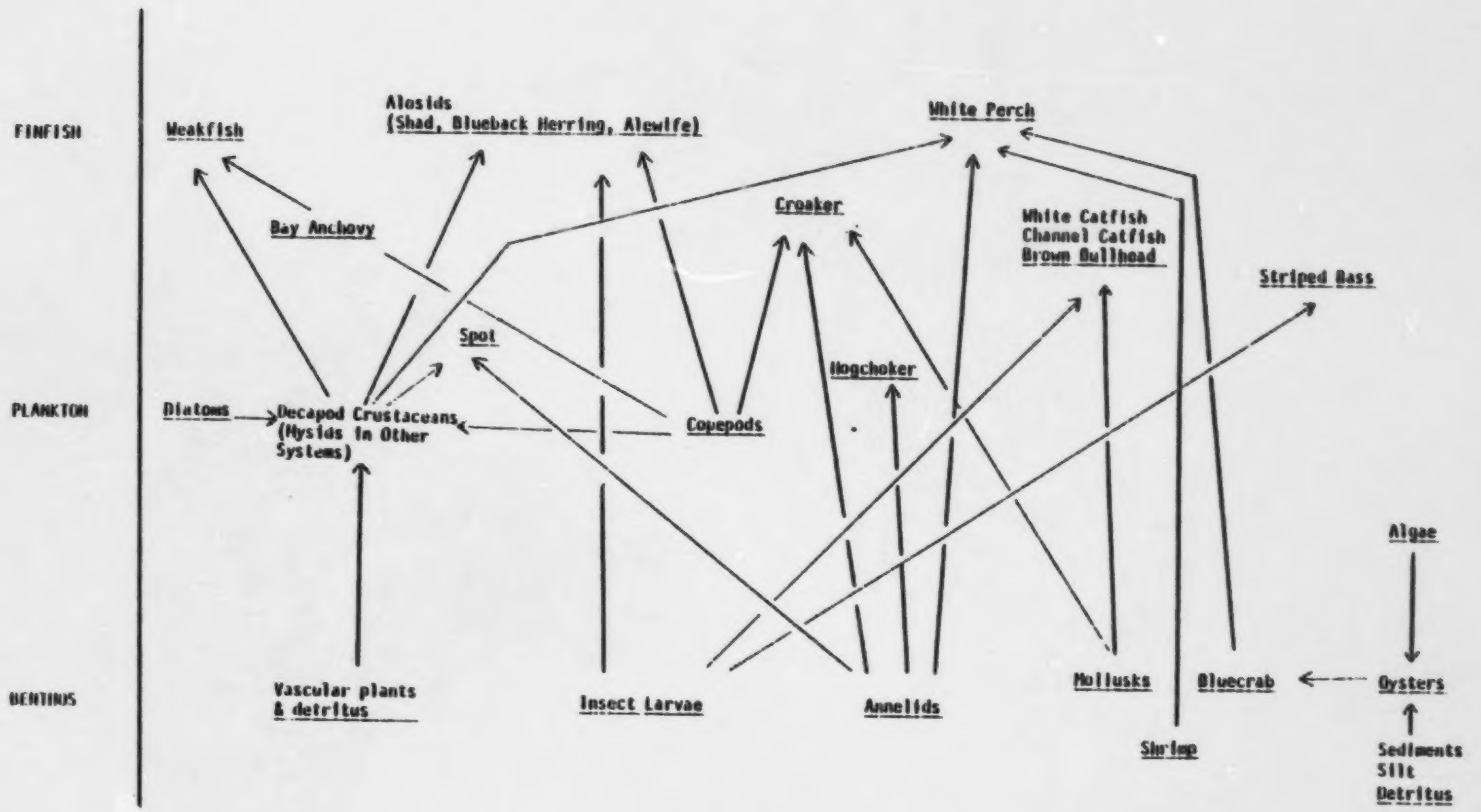

FINFISH
PLANKTON
BENTHOS
Weakfish
Alosids
(Shad, Blueback Herring, Alewife)
White Perch
Croaker
White Catfish
Channel Catfish
Brown Bullhead
Striped Bass
Bay Anchovy
Spot
Hogchoker
Diatoms
Decapod Crustaceans
(Mysids in Other
Systems)
Copepods
Algae
Vascular plants
& detritus
Insect Larvae
Annelids
Mollusks
Bluecrab
Oysters
Shrimp
Sediments
Silt
Detritus

Exhibit VI-4

Partial Food Web for Selected James River Species

The James River, which has supported several major commercial fisheries in the past, has witnessed the sharp decline in some of those fisheries during the early 1970's including blue crab, striped bass, white perch, and alewives. While some of these declines, such as the white perch, may represent fish kills, changes in fishing effort, etc., these populations generally have not recovered to previously established levels. Kepone may be a contributary substance which has been adversely affecting species and subsequently the food chains of the James River, thus creating conditions which are not condusive to the maintenance of viable fish and blue crab populations.

KEPONE MITIGATION CLEAN-UP INDICES

During 1976, ongoing studies at the Gulf Breeze Environmental Research Laboratory, and research studies supported by them, provided information on the organism effects of Kepone and processes which caused crabs, oysters, and fish to concentrate Kepone in their tissues at or above FDA Action Levels, making them unsafe for human consumption. This required a complete study of the effects of Kepone on representative species under laboratory conditions, and a correlation of these studies with information gathered from monitoring and field experiments. The results of this information were used to develop saltwater clean-up indices for Kepone to protect estuarine biota. It was recognized that the clean-up values should include consideration of production, use, chemical and physical properties, occurrence, and human health implications. However, the following indices consider only protection of aquatic life and uses of aquatic life. Also, these clean-up indices are based on the species most sensitive to Kepone, so that protection is afforded to the greatest number of species in the James River. Future determinations may show that such a comprehensive level of protection is not necessary to prevent Kepone uptake to Action Levels by a majority of the species. The unique situation in the James River estuary is that the major source of Kepone is recycled Kepone from the estuarine sediments. This required a modified approach with the development of separate values for aquatic food organisms and for sediment.

Derivation of Saltwater Clean-up Indices for Kepone

The estuarine fish, spot (Leiostomus xanthurus) is particularly sensitive to Kepone; the Final Fish Acute Value calculated from this species is 6.6 ug Kepone/l (ppb) of water. The Final Invertebrate Acute Value is 0.60 ug Kepone/l (ppb) of water. Consequently, the lower of the two, 0.60 ug Kepone/l (ppb) of water, becomes the Final Acute Value.

Chronic studies have been conducted on sheepshead minnows (Cyprinodon variqatus) and marine mysids. The Final Fish Chronic Value is <0.01 ug Kepone/l (ppb) of water; the Final Invertebrate Chronic Value is 0.008 ug Kepone/l (ppb) of water. Therefore, the Final Chronic Value is ≤0.008 ug Kepone/l (ppb) of water.

The marine alga, Chlorococcum sp., is the most sensitive plant species to Kepone; the Final Plant Value is <350 ug Kepone/l (ppb) of water.

The Residue Limited Toxicant Concentration (RLTC) is based on: (1) a study in which blue crab survival or molting was adversely affected after being fed a diet of oysters which contained 0.15 mg Kepone/kg (ppm) in tissue; and (2) an average bioconcentration factor of 7688. This RLTC is <0.019 ug Kepone/l (ppb) of water. As an index, the 24-hour average concentration should never exceed 0.008 ug of Kepone/l (ppb) of water.

It is important to emphasize that the data on the chronic effects of Kepone in fish, and the feeding studies on blue crabs provide "less than" values. Results of laboratory tests with crabs, shrimp, fish, and shellfish exposed only to Kepone in seawater underestimate the residues of Kepone measured in similar animals exposed to similar measured concentrations in the James River estuary. Therefore, the index is considered conservative.

Derivation of Food Clean-up Index for Kepone

Acute exposure of blue crabs (Callinectes sapidus) to Kepone in sea water in the Gulf Breeze Laboratory (Appendix C, No. 5) indicated relatively low toxicity and low bioconcentration. In contrast, monitoring data from the James River estuary indicated that blue crabs accumulated significant concentrations of Kepone. Gulf Breeze scientists found that the major route of Kepone entry was through contaminated food and not via water. Therefore, estimates of an index for contaminated food were developed.

Effects of Kepone on growth and survival of blue crabs fed oysters contaminated with Kepone are the only laboratory data demonstrating adverse effects of this pesticide in food on an aquatic organism (Appendix C, No. 14). Concentrations of 0.15 mg Kepone/kg (ppm) of oyster meat fed to blue crabs diminished survival or molting. However, because the data did not provide Gulf Breeze with a no-effect concentration, they applied a safety factor of 0.1 to this concentration to provide a clean-up index of 0.015 mg Kepone/kg (ppm) of tissue, which should be protective of consumer species.

A clean-up index of 0.015 mg Kepone/kg (ppm) in food organisms is far less than monitoring data revealed in animals from the James River estuary. An analysis of the monitoring data indicated that the average concentration of Kepone in fishes and invertebrates from the James River, which could be eaten by other organisms, ranged from 0.09 to 2.0 mg Kepone/kg of tissue. Gulf Breeze data on the effects of Kepone in oysters fed to blue crabs support the hypothesis that undesirable impacts on survival and molting of blue crabs are occurring in the James River.

Derivation of Sediment Clean-up Index for Kepone

The studies by VIMS, the State of Virginia, and Battelle clearly demonstrate that most of the discharged Kepone now resides in the sediments of the James River. The main sink for Kepone is in the turbidity maximum zone where suspended sediments are deposited. The concentrations of Kepone are orders of magnitude greater in the bed sediments than dissolved in river water. Gulf Breeze, VIMS (Appendix C, No. 12 and 16), and Battelle (Appendix A) have shown that partition equilibria for Kepone between sediment and water are directly affected by the sediment quality. Therefore, mitigation must first address Kepone in the sediments.

Clean-up indices for acceptable concentrations of Kepone in sediments have been derived by examining how Kepone partitions among water, sediments, and benthic biota. Experiments have shown that benthic organisms (lugworms, *Arenicola cristata*, and fiddler crabs, *Uca pugilator*), which ingested James River sediments with 0.250 mg Kepone/kg (ppm) of sediment, attained whole-body residues of 0.250 to 0.300 mg Kepone/kg (ppm) of tissue within 21 days. Lugworms did not survive exposure to these sediments after 21 days, and Kepone did not depurate from lugworms and fiddler crabs over a period of a few weeks in clean water (Bahner, *et al.*, in preparation). Concentrations as low as 2.8 ug Kepone/l (ppb) seawater caused a reduction in the normal soil reworking activity of the lugworm and 29.5 ug Kepone/l (ppb) seawater was acutely toxic within 144 hours to lugworms burrowing in sediments (Appendix C, No. 13). Since benthic organisms attained Kepone concentrations similar to the amount in sediments, and the food clean-up index is 0.015 mg Kepone/kg (ppm) of tissue, Kepone concentrations in sediment should not exceed 0.015 mg Kepone/kg (ppm) of sediment to insure that Kepone concentrations are less than the food clean-up index.

An alternate method of establishment of an acceptable concentration of Kepone in sediments can be based upon the premise that an equilibrium exists for Kepone between the sediment and water [Kp = (ug/kg sediment)/(ug/l water)]. An examination of laboratory Kp-values indicates numbers ranging from 2.5 to 1700 (Appendix A; Appendix C, No. 12 and 17). If pure reference clays and sand are ignored (Kp = 2.5-50), the range is between 100 to 1700 and is related to the quality and quantity of organic material in the sediment. Using these values to derive acceptable sediment concentrations, with the previously derived Kepone water clean-up index of ≤0.008 ug Kepone/l (ppb) of water yields a range of 0.0008 to 0.014 mg Kepone/kg (ppm) in sediment. (The average concentration of Kepone in James River sediments from December 1976 through July 1977 was 0.150 mg Kepone/kg (ppm) of sediment).

If a Kepone partition between water and James River sediment of Kp=1000 is utilized, concentrations of 0.008 mg Kepone/kg (ppm) of sediment would result in equilibrium concentrations equal to the water clean-up index of 0.008 ug Kepone/l (ppb) of water. Since the food clean-up index is 0.015 mg Kepone/kg (ppm) of tissue, the concentration of Kepone in sediment must not exceed 0.015 mg Kepone/kg (ppm) of sediment. With the lower limit of analytical detection for Kepone in sediments usually placed at 0.02 mg Kepone/kg (ppm) of sediment, both of the derived concentrations are below analytical detection. Therefore, if Kepone is present in measurable quantities, it is hazardous to aquatic life.

VII. KEPONE PROBLEM PROJECTIONS

A full assessment of the Kepone contamination problem in the Hopewell/James River area must consider the immediate and long-range impacts on persons and on the environment. Previous chapters have focused primarily on the nature of the current Kepone contamination problem. This chapter describes the predicted movement of contaminated sediments and water in the James River and the implications of Kepone's continued presence.

KEPONE TRANSPORT PROJECTIONS

The (FETRA) computer model, discussed in Chapter IV, was employed in combination with the EXPLORE hydrodynamic code to predict the transport of Kepone in the tidal James River. The model was applied to an 86-kilometer reach between City Point (river kilometer 123) and Burwell Bay (river kilometer 37). Burwell Bay, rather than the river mouth, was designated as the lower boundary because of limitatons in the field data and hydrodynamic code. The percentage, if any, of Kepone migrating past Burwell Bay which would settle out or sorb onto bottom sediments between Burwell Bay and the mouth of the James River is unknown. Therefore, projections of Kepone transport past Burwell Bay represent an upper limit to the predicted amount of Kepone subsequently passing into Chesapeake Bay.

Three flow discharge cases measured at City Point were simulated: (1) a freshwater discharge of 58.3 m³/sec (2,050 cfs); (2) a freshwater discharge of 247 m³/sec (8,700 cfs); and (3) a freshwater discharge of 681 m³/sec (24,000 cfs). The freshwater input discharge of 58.3 m³/sec at City Point corresponds to that of approximately the 10 percentile discharge (i.e., 10 percent of the time of the year the freshwater input discharge is 58.3 m³/sec or less). The second discharge of 247 m³/sec roughly corresponds to the average annual discharge, and the third discharge of 681 m³/sec corresponds to approximately the 90 percentile discharge.

The major results from the model are presented in Exhibits VII-1 through VII-5. Exhibit VII-1 shows the predicted daily migration of Kepone under the different flow regimes past Burwell Bay in the lower James estuary. During average flow conditions, an estimated 170 grams per day of Kepone are transported past Burwell Bay. Model output shows that roughly 80 percent of this Kepone exists in the dissolved state, with the other 20 percent attached to mobile sediments. During high flow this total increases to 548 grams/day, with a slight increase in the percentage attached to sediment.

Exhibit VII-2 displays the results of combining these daily flow estimates into different runoff years. Calculations show that between 52 kg (114.4 lb.) and 126 kg (277.2 lb.) of Kepone are being transported past Burwell Bay in each year, with an average range of 71 kg (156.2 lb.) to 89 kg (195.8 lb.) per year.

EXHIBIT VII-1

Daily Kepone Transport Projections

Condition	Average Daily Flow Rate	Kepone Transport Past Burwell Bay
Low Flow	2,050 cfs (58.3 m /sec)	38 grams/day
Average Flow	8,700 cfs (247 m /sec)	170 grams/day
High Flow	24,000 cfs (681 m /sec)	548 grams/day

EXHIBIT VII-2

Annual Kepone Transport Projections

	Percentage of Days Per Year James River Flow Averages:			
Condition	2,050 cfs	8,700 cfs	24,000 cfs	Kepone Transport Past Burwell Bay
Low Flow Year	50%	40%	10%	52 kg/yr
Average Flow Year	10%	80%	10%	71 kg/yr
Average Flow Year	30%	40%	30%	89 kg/yr
High Flow Year	10%	40%	50%	126 kg/yr

Also, since Kepone is concentrated in migratory biota, it physically moves in the water system along with the host. The magnitude of the amount of Kepone transported by migratory fish was determined. Catch-per-unit-effort information was supplied by VIMS for summer and winter surveys. The application of these data to estimating the Kepone transport required the following assumptions: (1) all of the migratory fish populations that were present during the survey leave the system, and (2) these fish are in the James River long enough to accumulate equilibrium levels of Kepone where depuration just cancels further uptake. The estimates of Kepone transported annually in the major species is an average of 72 kg (158 lb) and a maximum of 225 kg (494 lb).

Exhibits VII-3 through VII-5 show the predicted concentrations of Kepone existing in James River water between City Point and Burwell Bay under the three flow regimes. Values are expressed in micrograms of Kepone per liter of water (ppb) and are averaged over a full tidal cycle. Under average flow conditions (Exhibit VII-4) Kepone levels in the water are seen to peak near the Jamestown area where slightly more of the mobile Kepone is attached to suspended sediments than is dissolved. However, the amount of Kepone transported in sediments drops sharply down river resulting in a large majority of Kepone exiting Burwell Bay in the dissolved state.

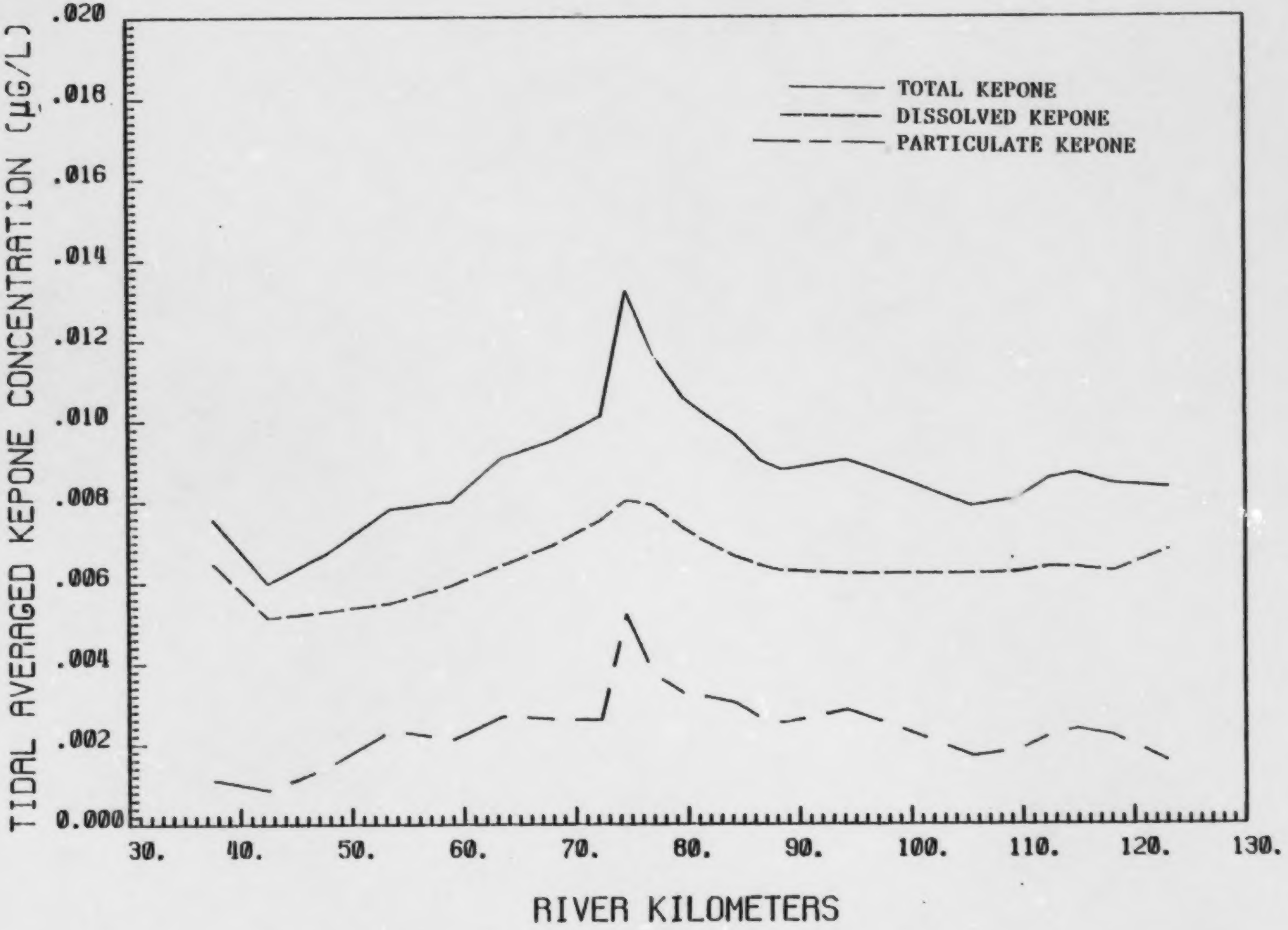


Exhibit VII-3 Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

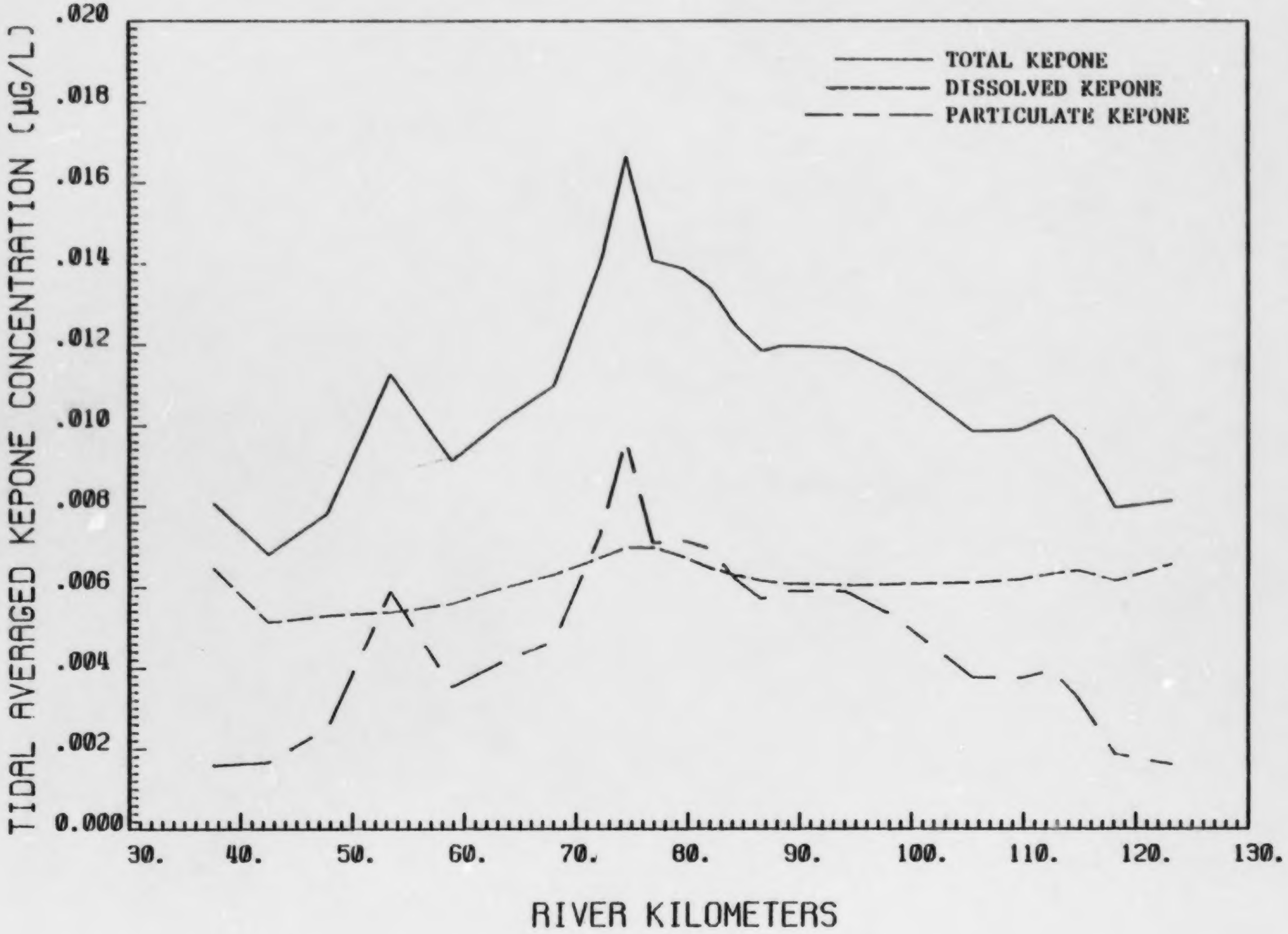


Exhibit VII-4 Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 247 m^3/sec

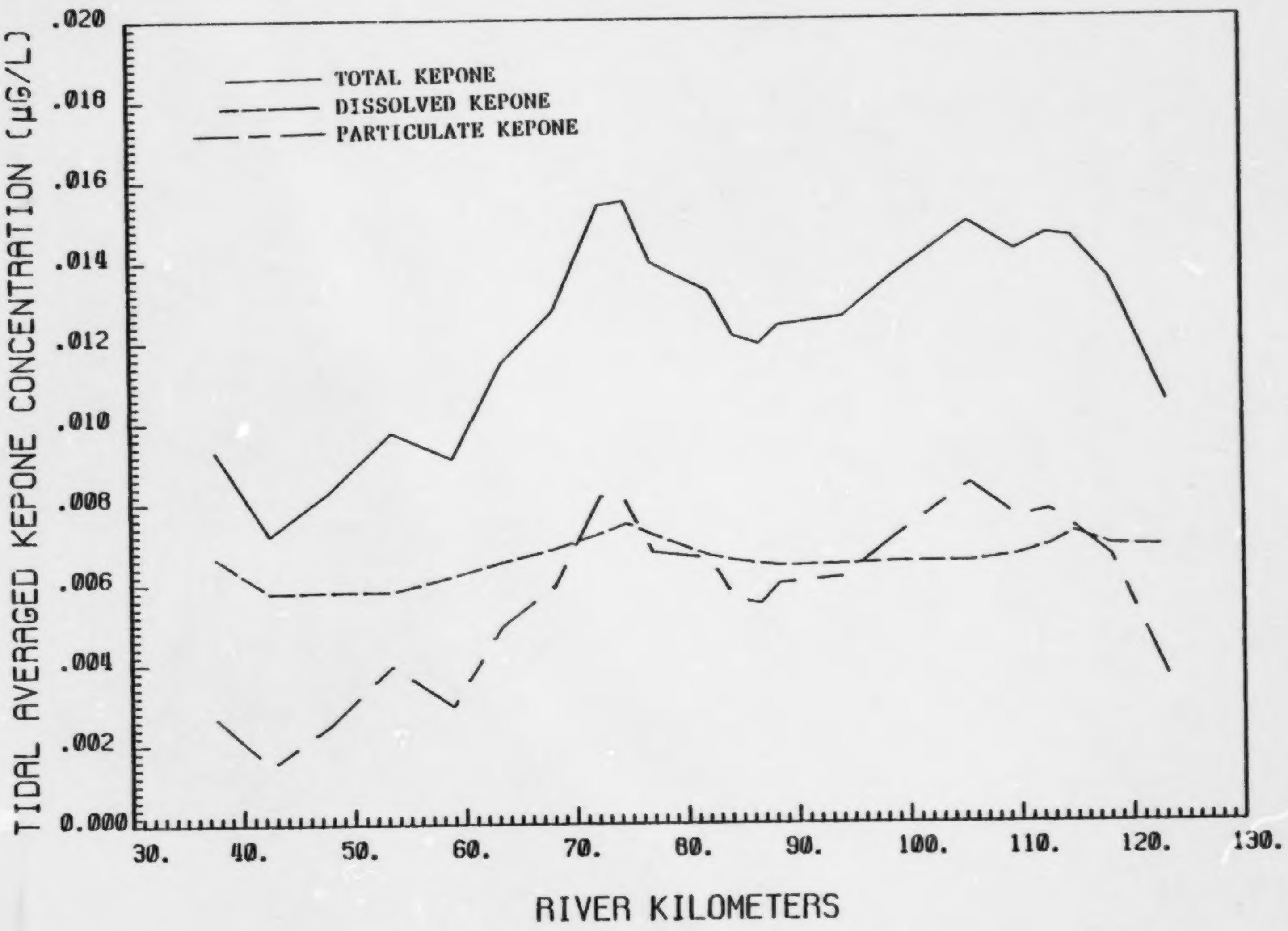


Exhibit VII-5 Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 681 m^3/sec

In the following sections, the calibration and verification of the model are presented. Results of sensitivity analyses can be found in Chapter VII of the Battelle report (Appendix A), as well as additional model output, including predicted levels of suspended sediment in the tidal James River and scour/deposition rates under the different flow regimes.

Calibration of the Model

Calibration of a mathematical model is one of the most important aspects of the simulation process. Calibration is usually performed by "tuning" a model to reproduce a known condition by adjusting some model parameters. As shown in Exhibit VII-6, in the present study most of the parameters (such as Kepone distribution coefficients, turbulent diffusion coefficient, sediment sizes, sediment fall velocity, etc.) were fixed not only by adjusting them to match computer results with field data, but also, they were determined by theoretical and experimental analyses and field conditions, prior to the model simulation. Hence, the only parameters which can be changed to fit simulation results to the measured data are a dispersion coefficient and three parameters which calculate deposition and erosion rates of sediment. Thus, the major calibration effort was directed to reproducing sediment distribution patterns similar to the actual longitudinal distribution of sediment concentrations for the

Exhibit VII-6 TEST CONDITIONS FOR KEPONE SIMULATION

	Case 1	Case 2	Case 3
Fresh-water Discharge (m^3/sec)	58.3	247	681
River Sediment Size (mm)			
Cohesive sediment	0.030	0.030	0.030
Organic matter	0.100	0.100	0.100
Sand	0.150	0.150	0.150
Longitudinal Dispersion Coefficients for all Sediment and Kepone (m^2/sec)	14	14	14
Longitudinal Diffusion Coefficients for all Sediment and Kepone (m^2/sec)	0.14	0.14	0.14
Kepone Decay Rate (1/hr)	0	0	0
Kepone Distribution Coefficients (cm^3/g)			
Associated with cohesive sediment	10,000	10,000	10,000
Associated with organic matter	20,000	20,000	20,000
Associated with sand	1,000	1,000	1,000
Kepone Mass Transfer Rate (1/hr)	1	1	1
Initial Bed Sediment Constituents (%)			
Cohesive sediment	80	80	80
Organic Matter	15	15	15
Sand	5	5	5
Boundary Conditions During Ebb Tide			
Sediment Concentrations at City Point (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	3.2
Kepone Concentrations at City Point			
Dissolved (ug/ℓ)	0.007	0.007	0.007
Particulate (ug/g) associated with			
Cohesive sediment	0.045	0.045	0.045
Organic Matter	0.090	0.090	0.090
Sand	0.0045	0.0045	0.0045
Boundary Conditions During Flood Tide			
Sediment Concentrations at Burwell Bay (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	
Kepone Concentrations at Burwell Bay			
Dissolved (µg/ℓ)	0.007	0.007	0.007
Particulate (µg/g) associated with			
Cohesive sediment	0.032	0.032	0.032
Organic matter	0.064	0.064	0.064
Sand	0.0032	0.0032	0.0032

86-km study reach measured by Battelle during the June 1977, James River sampling effort.

As a result of numerous trial runs after adjusting the parameters, data were obtained for final calibration for the freshwater discharge of 58.3 m^3/sec as shown in Exhibit VII-7 to VII-9. These figures show computed longitudinal variation of total sediment concentrations (sum of cohesive sediment, organic matter and sand being transported as suspended and bed loads) at maximum ebb, slack tide and maximum flood, together with measured data obtained by Battelle for the same freshwater discharge. Comparison of the computer results with the measured data indicate excellent agreement. Although it is possible to improve the model prediction with more fine tuning, it was judged that the model was calibrated successfully.

Verification of the Model

Model verification was undertaken through a comparison of model results at a given flow rate with previously acquired field data at similar flow rates.

Verification of the sediment transport part of the model was conducted for Case 2 (freshwater discharge of 247 m^3/sec). Model results are shown in Exhibits VII-10 and VII-11, together with field data. These figures include sediment concentrations of each type of

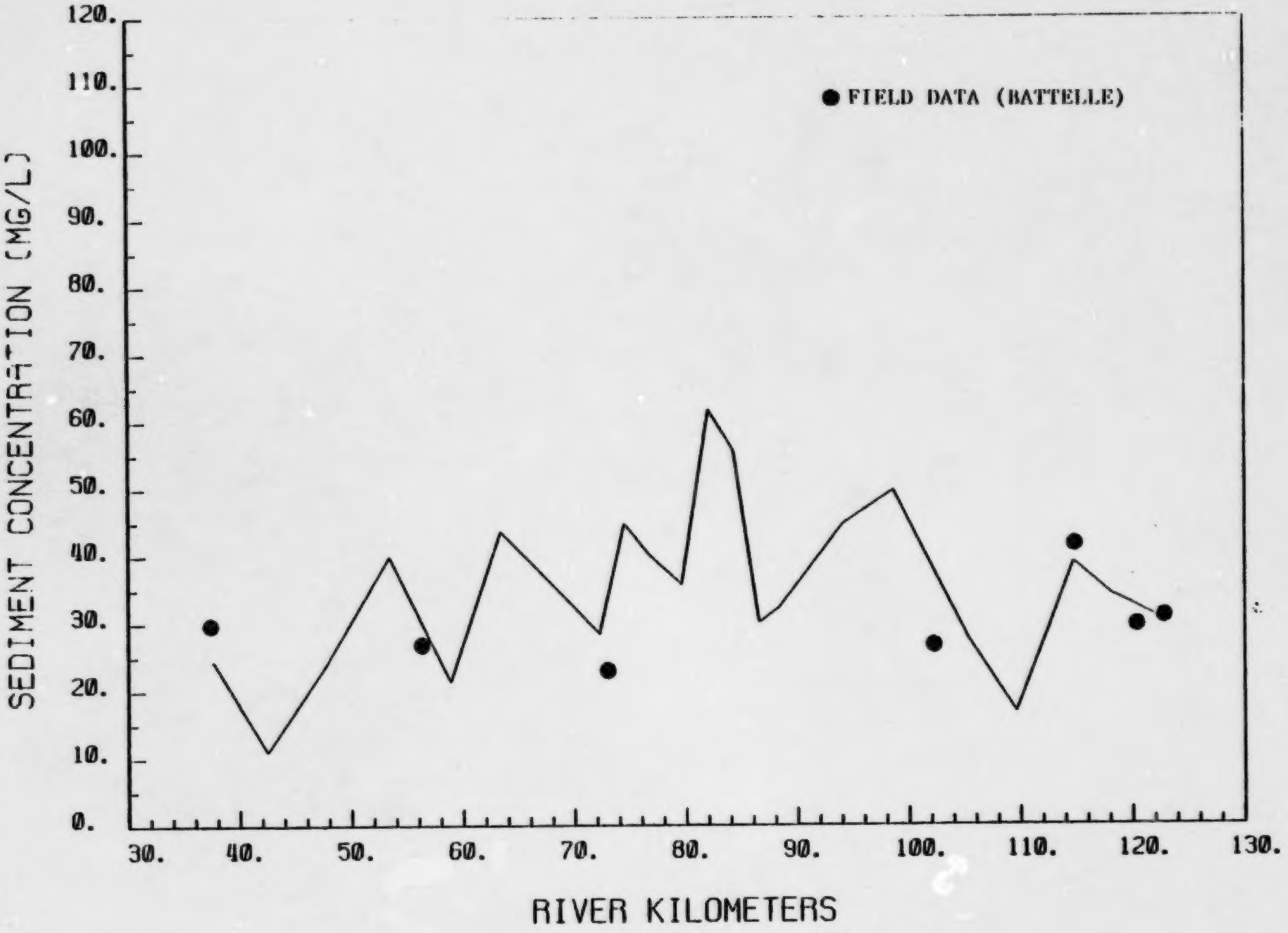


Exhibit VII-7 Longitudinal Distributions of Total Sediment Concentration at the Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

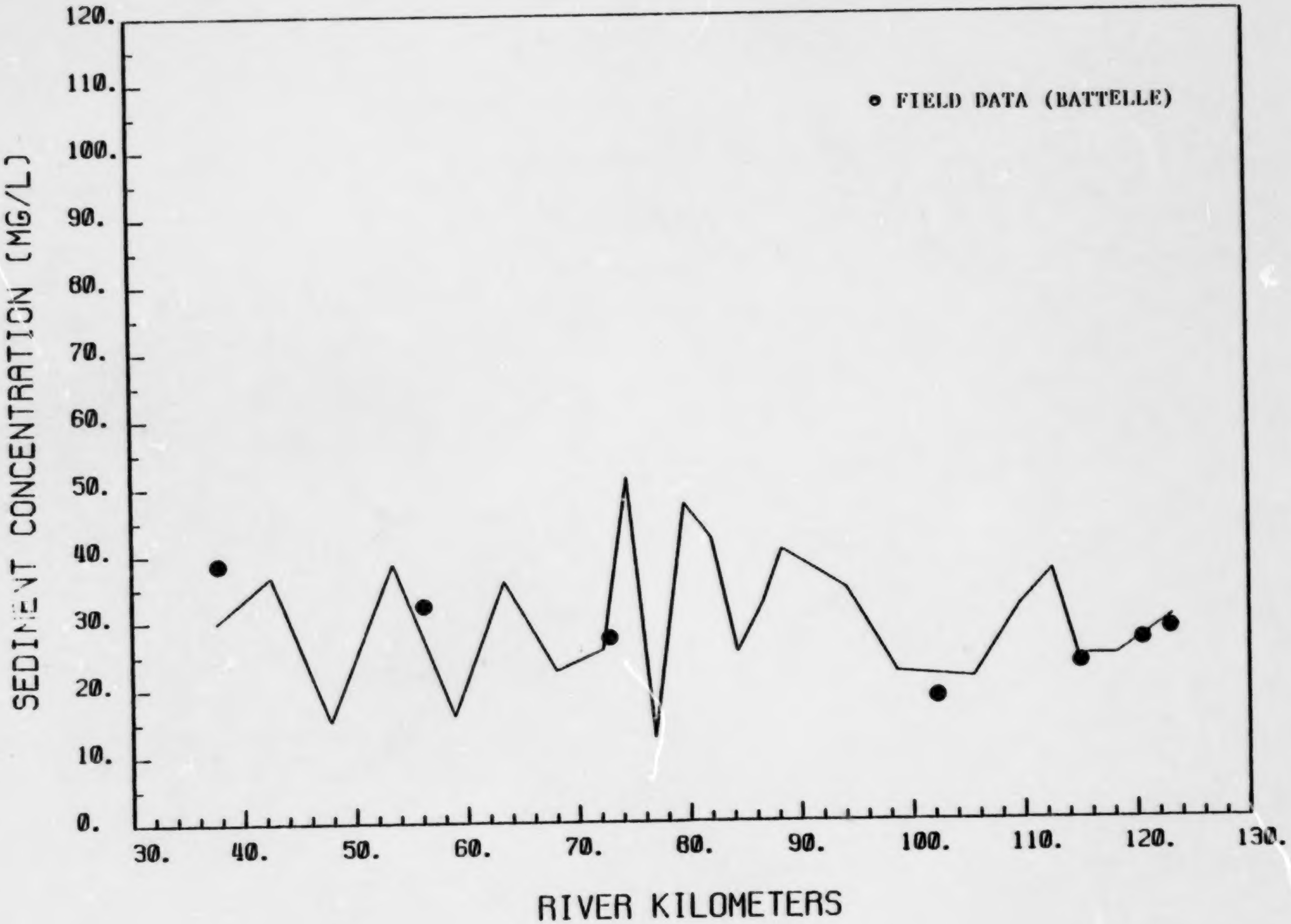
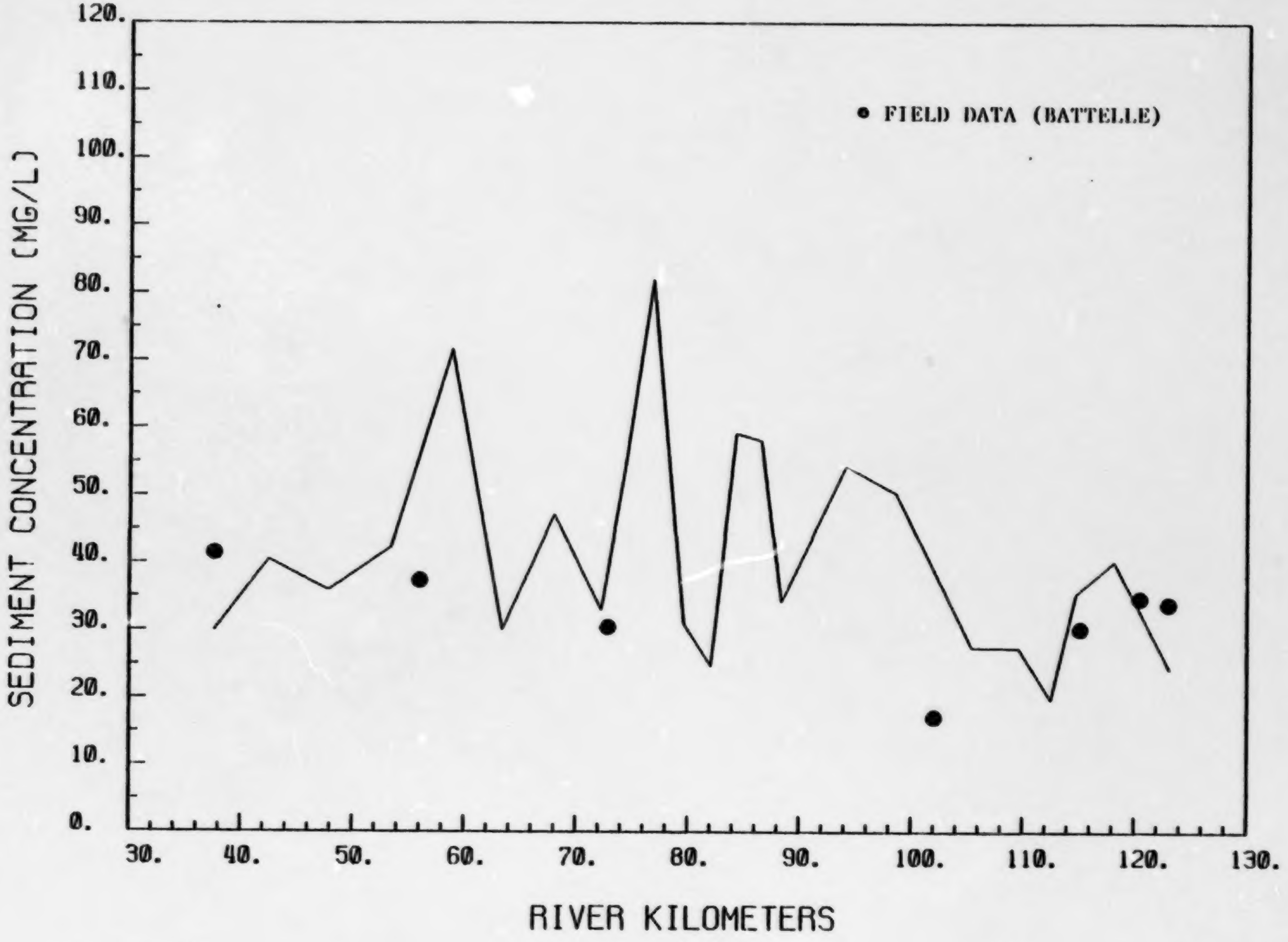


Exhibit VII-8 Longitudinal Distributions of Total Sediment Concentration at the Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data



ExhibitVII-9 Longitudinal Distributions of Total Sediment Concentration at the Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

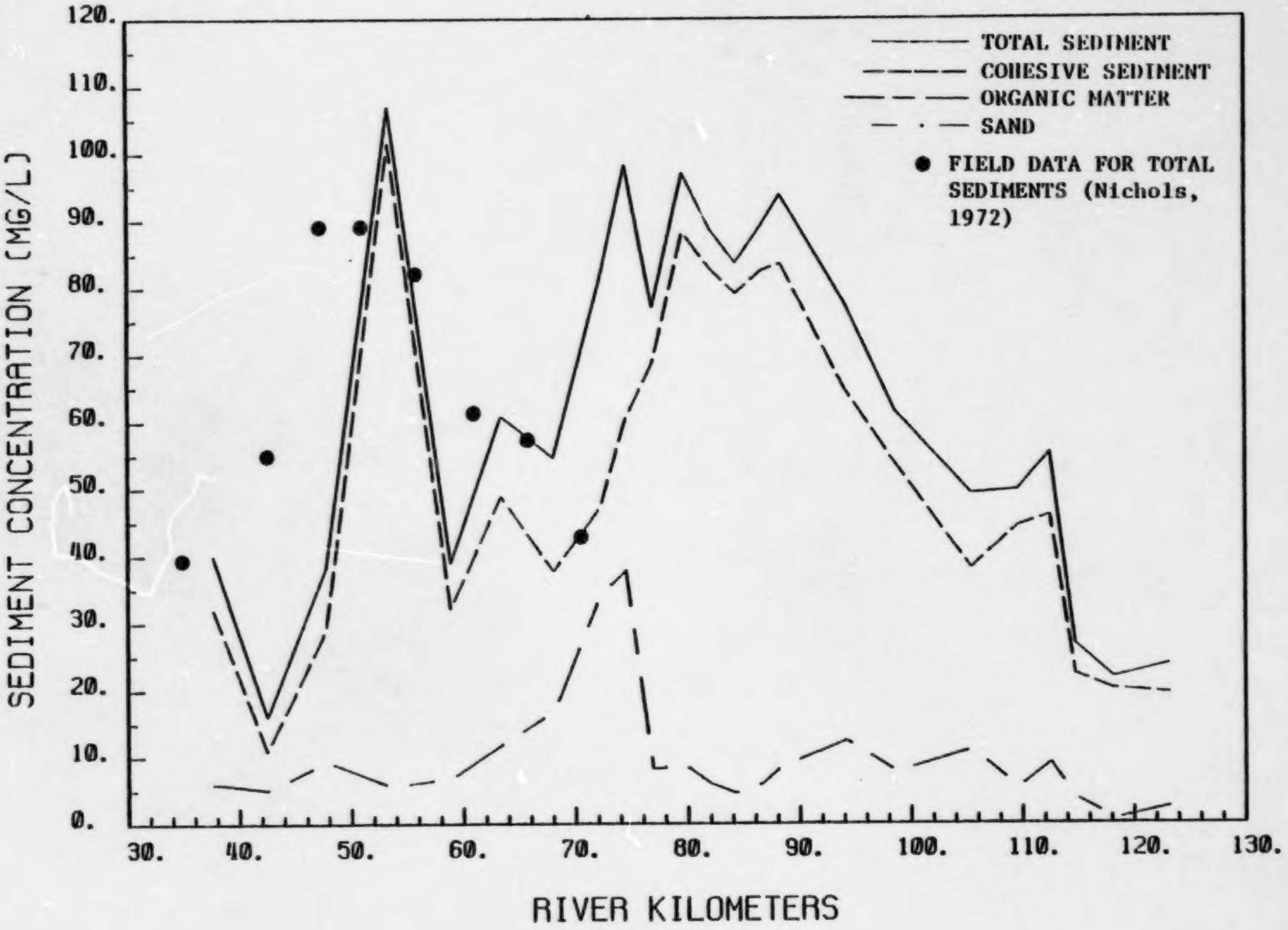


Exhibit VII-10 Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

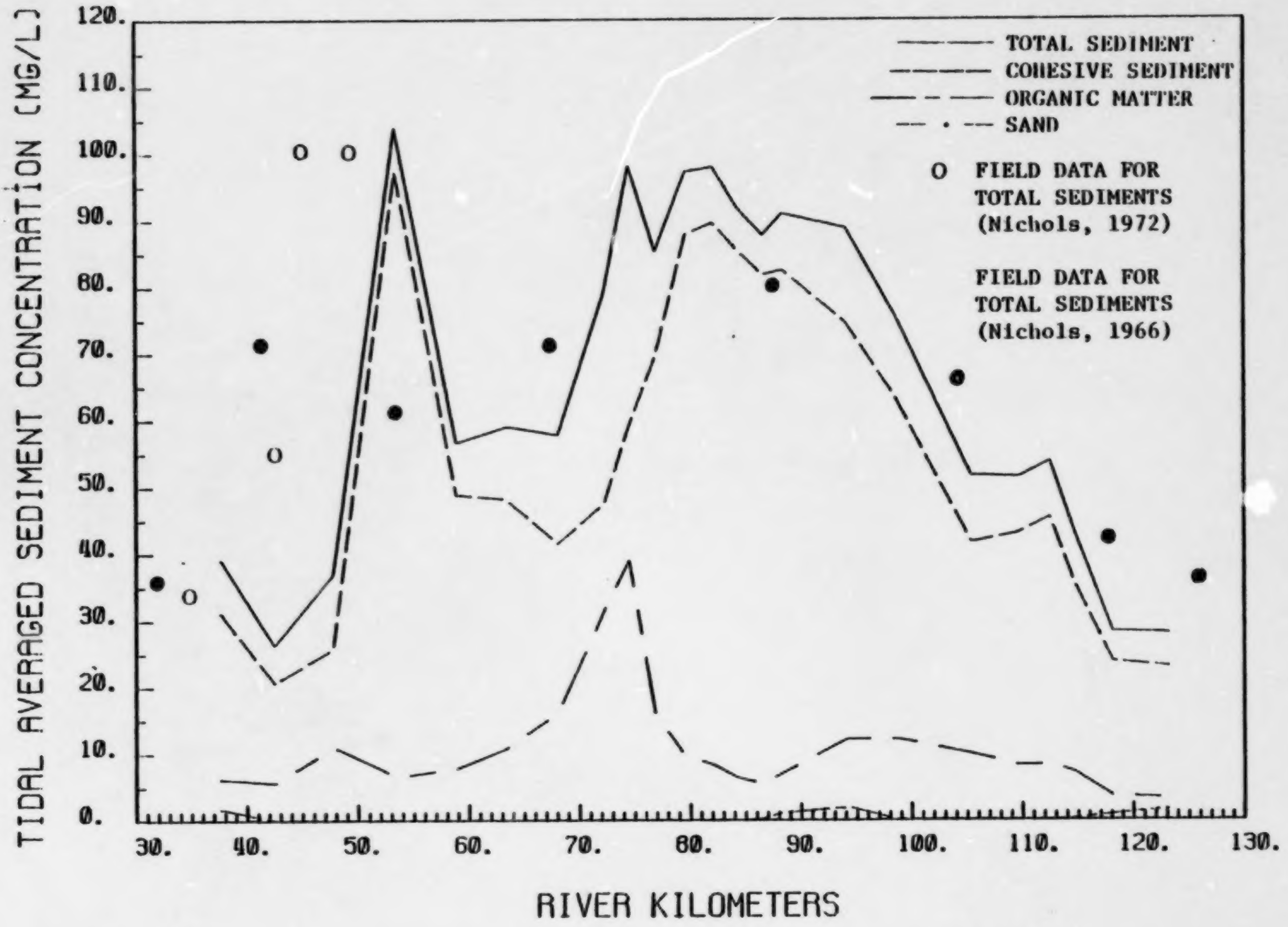


Exhibit VII-11 Tidal Averaged Sediment Concentration of Each Sediment Type for the Freshwater Discharge of 247 m^3/sec

sediment (cohesive sediment, organic materials or sand) and total sediment (sum of those sediment components). Measured total sediment concentrations in these figures were obtained by Nichols (1972) in March 1965 and March 1960. Field data in 1966 were provided by Nichols through personal communication. Field data in 1965 were those associated with a freshwater input discharge of 250 m^3/sec, while 1966 data were obtained in two days during which the freshwater input discharge changed from 257 m^3/s to 144 m^3/sec with the two-day average discharge being 201 m^3/sec. (The present simulation was conducted for the discharge of 247 m^3/sec). Comparison of these field data with computer results at slack tide and tidal average cases (Exhibits VII-10 and VII-11) indicate excellent agreement among these values. Since the present model was calibrated for the discharge of 58.3 m^3/sec and the model was not readjusted for the 247 m^3/sec case, this excellent agreement with measured data for the latter case provides additional confidence in the sediment transport part of the model.

Verification of the Kepone transport part of the model was conducted by comparing computer results to measured data obtained by Battelle and VIMS for case 1 (freshwaster discharge of 58.3 m^3sec). As noted previously, Battelle's data were obtained during June 1977 and VIMS data were collected during August 1977. Since there were no parameters adjustable to fix the computer results to those field data, numerical comparison cannot be made. However, the trends of the field data and computer results are similar. This correlation provides an additional basis for confidence in the verification. Exhibits VII-12 through VII-14 present predicted particulate Kepone concentrations associated with each type of sediment and average particulate Kepone (weighted average of three particulate Kepone values associated with the three sediment types) per unit weight of sediment, together with cross-sectionally averaged field data of average particulate Kepone concentrations. These were obtained by Battelle for maximum ebb, slack and flood tides, respectively.

Exhibits VII-15 and VII-16 present predicted tidally averaged particulate Kepone concentrations per unit weight of suspended sediment, and those per unit volume of water, respectively, together with measured average particulate Kepone concentrations obtained by Battelle and VIMS in their James River sampling effort. As noted above, Battelle's data in these figures are cross-sectionally averaged values. However, VIMS data are those measured in a main navigation channel of the river. Except for the maximum flood tide case (Exhibit VII-14), the agreement between the computer results and the field data are good. For example, Exhibit VII-16 reveals excellent agreement except one measured point at river kilometer 111. A suggested explanation by Battelle of the discrepancy between the predicted and measured value at river kilometer 111 is as follows: in the uppermost part of the river, Kepone distribution in suspended sediment across the river is much less uniform, as compared to distributions in the lower part of the James River because of the short distance from the

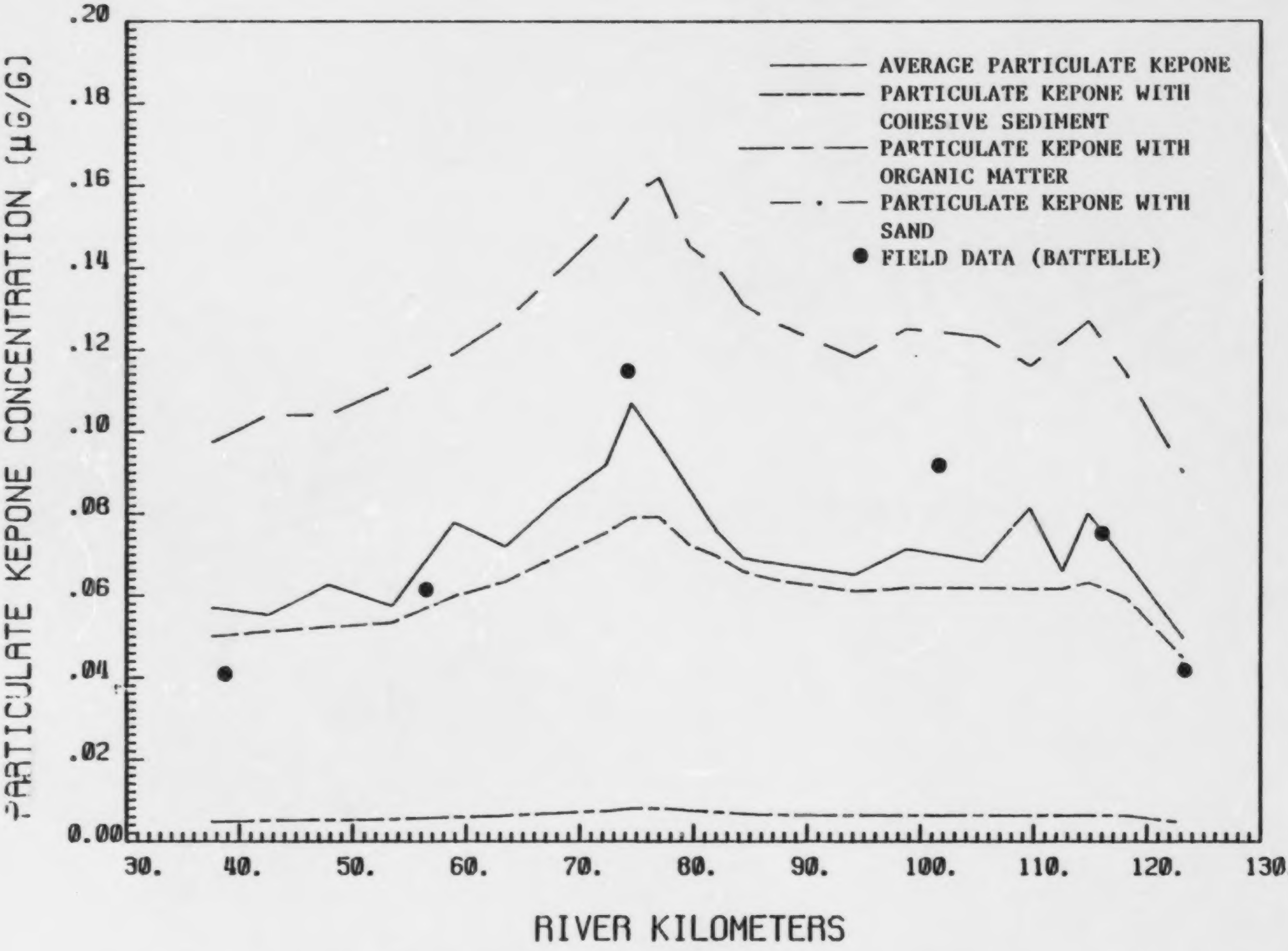


Exhibit VII-12 Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge to 58.3 m^3/sec

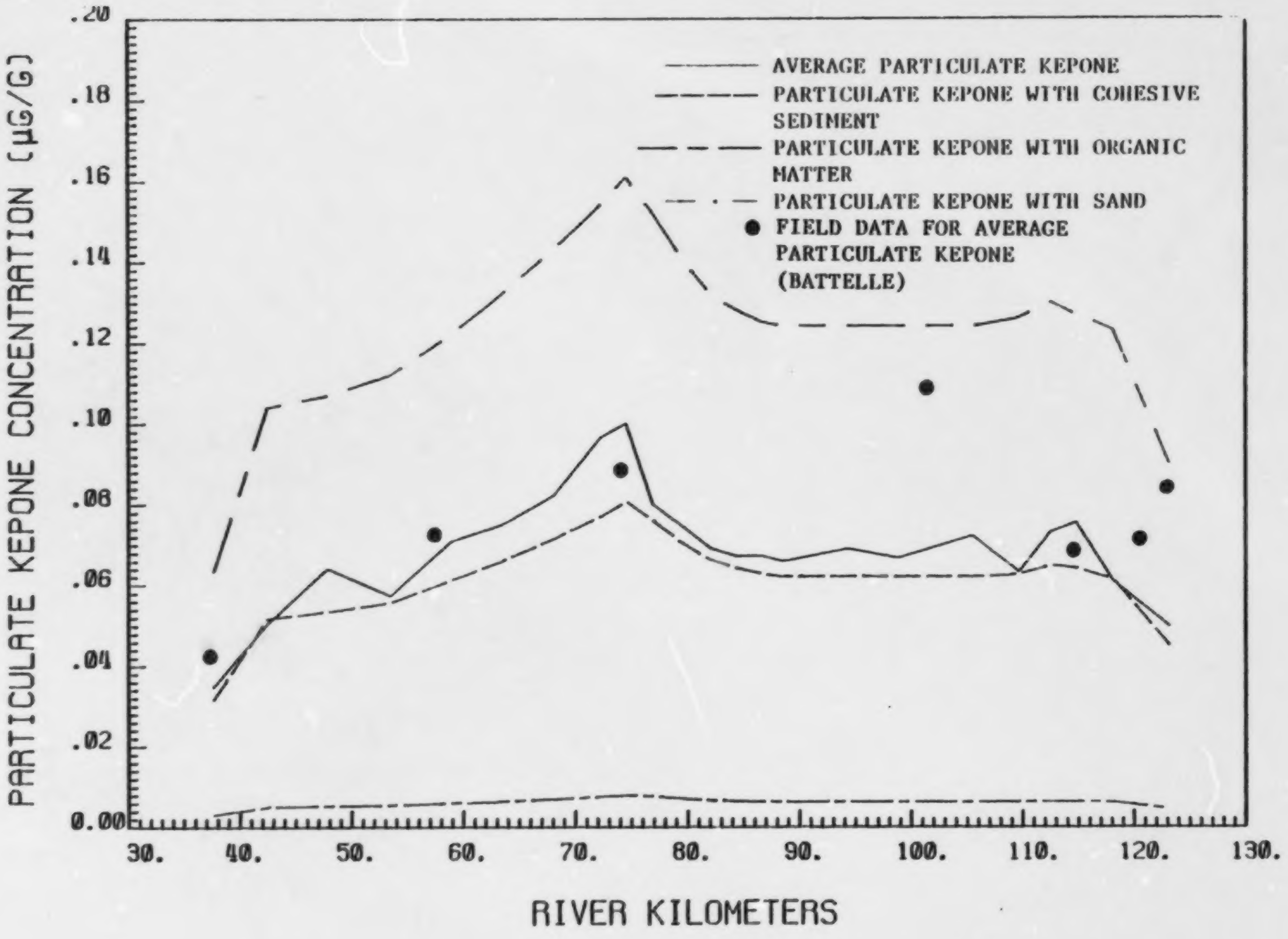


Exhibit VII-13 Longitudinal Distributions of Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

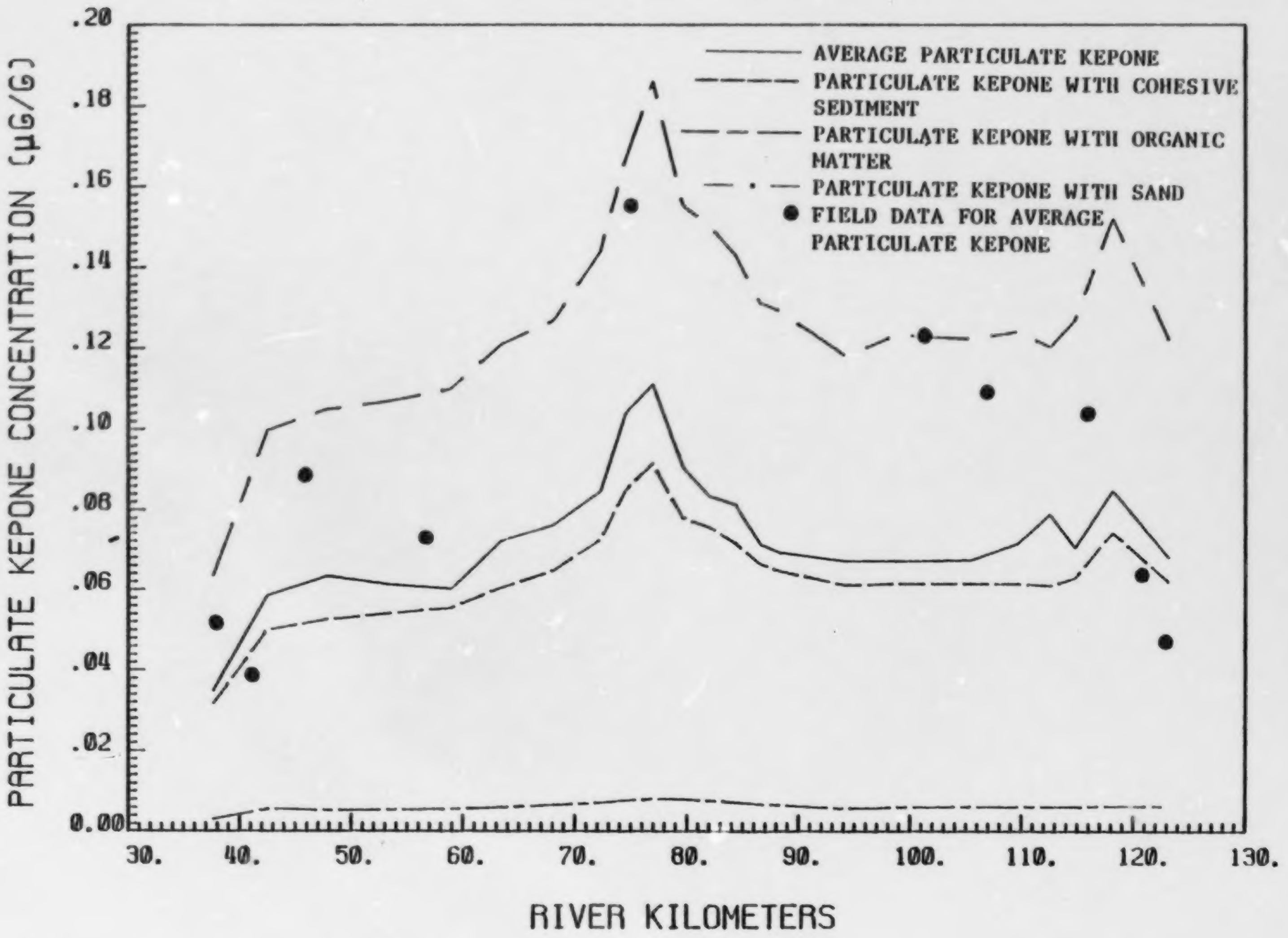


Exhibit VII-14 Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

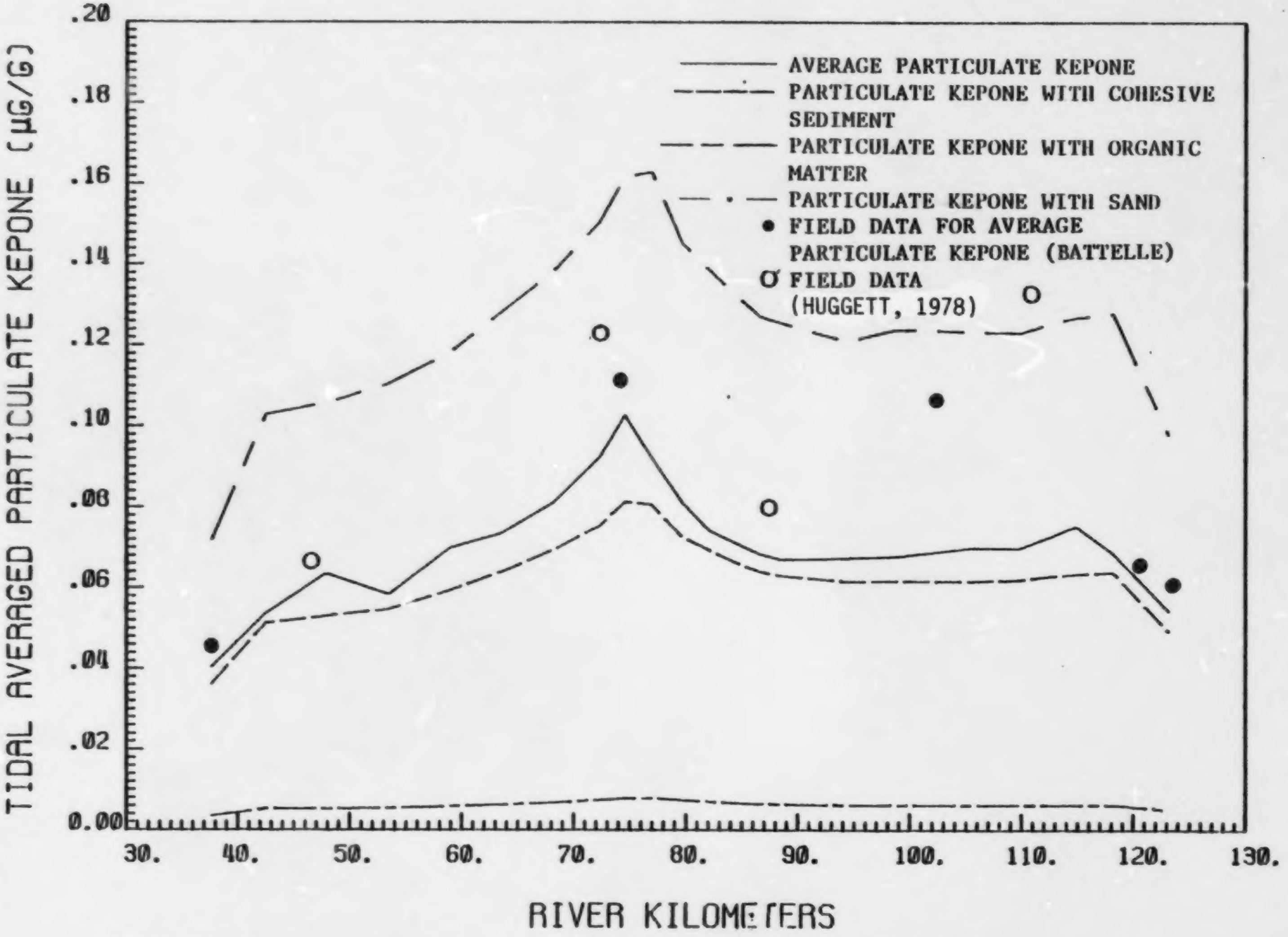


Exhibit VII-15 Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

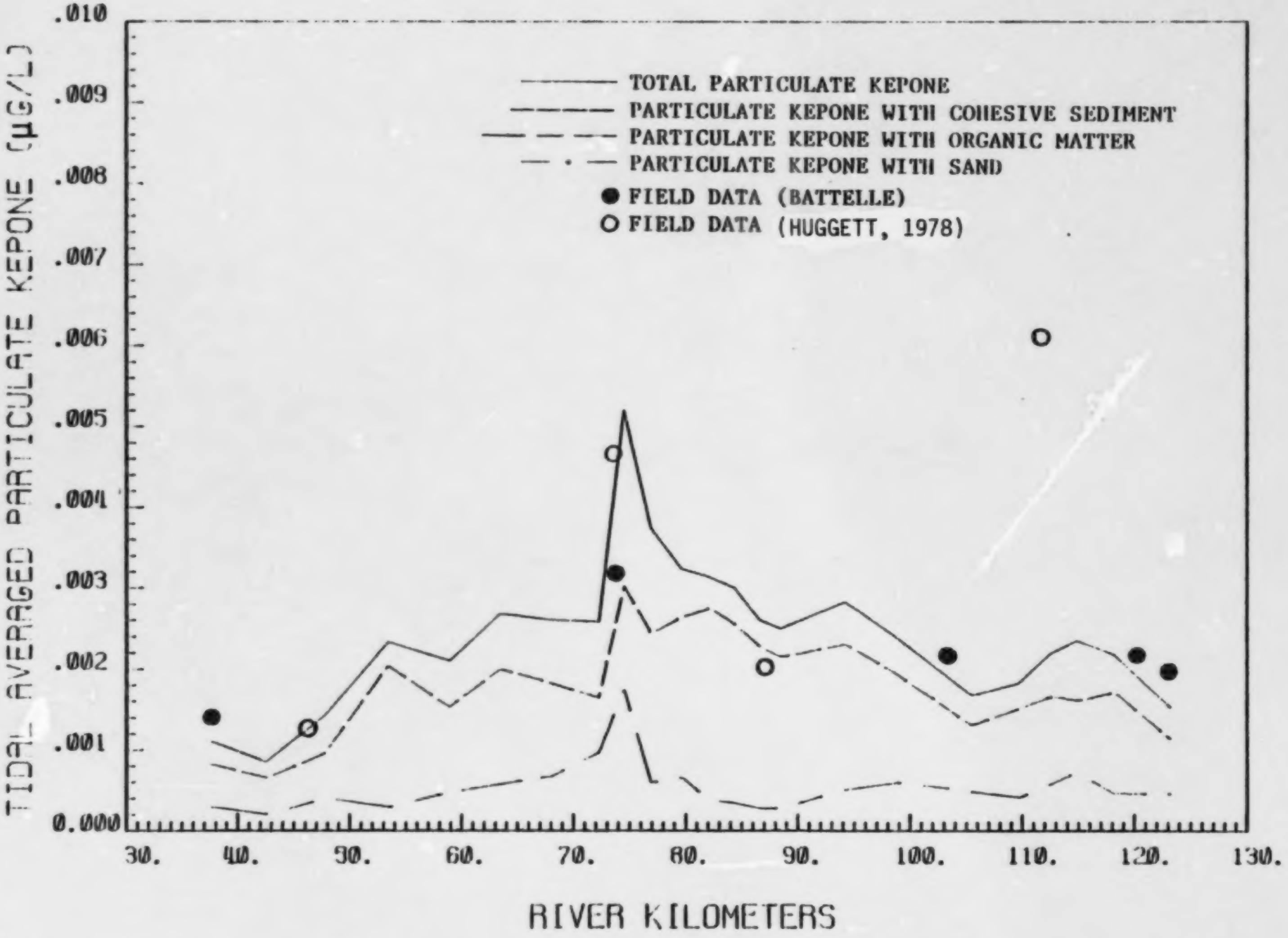


Exhibit VII-16 Longitudinal Distributions of Tidal Averaged Particulate Kepone Concentrations per Unit Volume of Water for the Fresh-water Discharge of 58.3 m^3/sec

original Kepone discharge source (at Hopewell). Hence, VIMS data obtained in a main channel of the river kilometer 111 is expected to be higher than a cross-sectional average there. However, in the lower part of the river, the measured data in the main channel may be much closer to the cross-sectional average. This trend may be reflected in Exhibit VII-16, when the computed and measured values are compared. From the comparisons shown in Exhibit VII-12 through VII-16, it is judged that the particulate Kepone transport part of the model has been verified with sufficient field data.

Most of the dissolved Kepone concentrations measured in the James River reach were below the detection limit which is approximately 0.005 to 0.010 ug/l. VIMS also reported from their August 1977 field sampling that the dissolved Kepone level in the James River is below the detection limit. Hence in this study, dissolved concentrations at the head end of the study reach was set to 0.007 ug/l, which is approximately the highest possible value maintained in the river. Exhibit VII-3 shows the computed tidal averaged dissolved Kepone concentration together with particulate and total (sum of dissolved and particulate) Kepone concentrations. This exhibit indicates that dissolved Kepone concentrations vary from approximately 0.0049 to 0.0080 ug/l. As stated above, from the measured particulate Kepone concentration and the Kd value, expected dissolved Kepone concentration is somewhat below the detection limit but is roughly the same order of magnitude to the detection limit. Hence, the predicted level of dissolved concentration by the FETRA code is the highest possible value found in the study area but still below the detection limit. From these considerations, the dissolved Kepone transport part of the FETRA code was also judged to be reasonably well verified with available information on dissolved Kepone concentrations in the James River estuary.

Simulation of Alternatives

Two important questions to be asked are:

1. What will happen to the Kepone migration pattern and its concentration level if a part of Kepone in the river bed is removed by physical, chemical or biological methods?

2. Where is the most optimal location for Kepone removal to reduce the Kepone level in the river?

In order to answer these questions, mathematical modelling was conducted for an additional ten cases (Cases A through J) by assuming that for each case, Kepone in the bed at a certain part of the Tidal James River was completely removed. For all cases, freshwater input discharges were assumed to be 247 m^3/sec. Computer results during the maximum ebb tide after one-month simulation for these cases were then compared with the no-cleanup action case in order to assess effectiveness of the Kepone cleanup activities.

Locations of Kepone cleanup activities were divided into four categories: (1) upper part of the tidal James River (Cases A, B, and C); (2) middle part of the river (Cases D through H); (3) lower part of the river (Case I); and (4) combination of (2) and (3) (Case J). Exact cleanup locations are shown in the lower parts of Exhibits VII-17 through VII-19, together with simulation results. Total dissolved and particulate Kepone concentrations for Cases A through J and Case 2 (247 m^3/sec) flow rate with no sediment removal, are also shown in Exhibits VII-17 through VII-19, respectively.

In the cases of removal of contaminated sediment from upper river areas (Cases A through C), Case B (cleanup of Bailey Bay and the upper half of Tar Bay) and Case C (Bailey and Tar Bays) improve the situation by reducing the Kepone level in water by approximately 15 percent within the vicinity of the cleanup locations. Case A (cleanup of Bailey Bay) would remove all Kepone from this source, but it would have little impact in the short term on the total amount of Kepone leaving Burwell Bay.

For middle river cleanup activities (Cases D through H), reductions of up to 55 and 48 percent of Kepone in water were obtained for Cases D and E, respectively. Case D cleanup area is an area of 34.5 km between 50.5 and 85.0 River Kilometer, and Case E is a 20-km

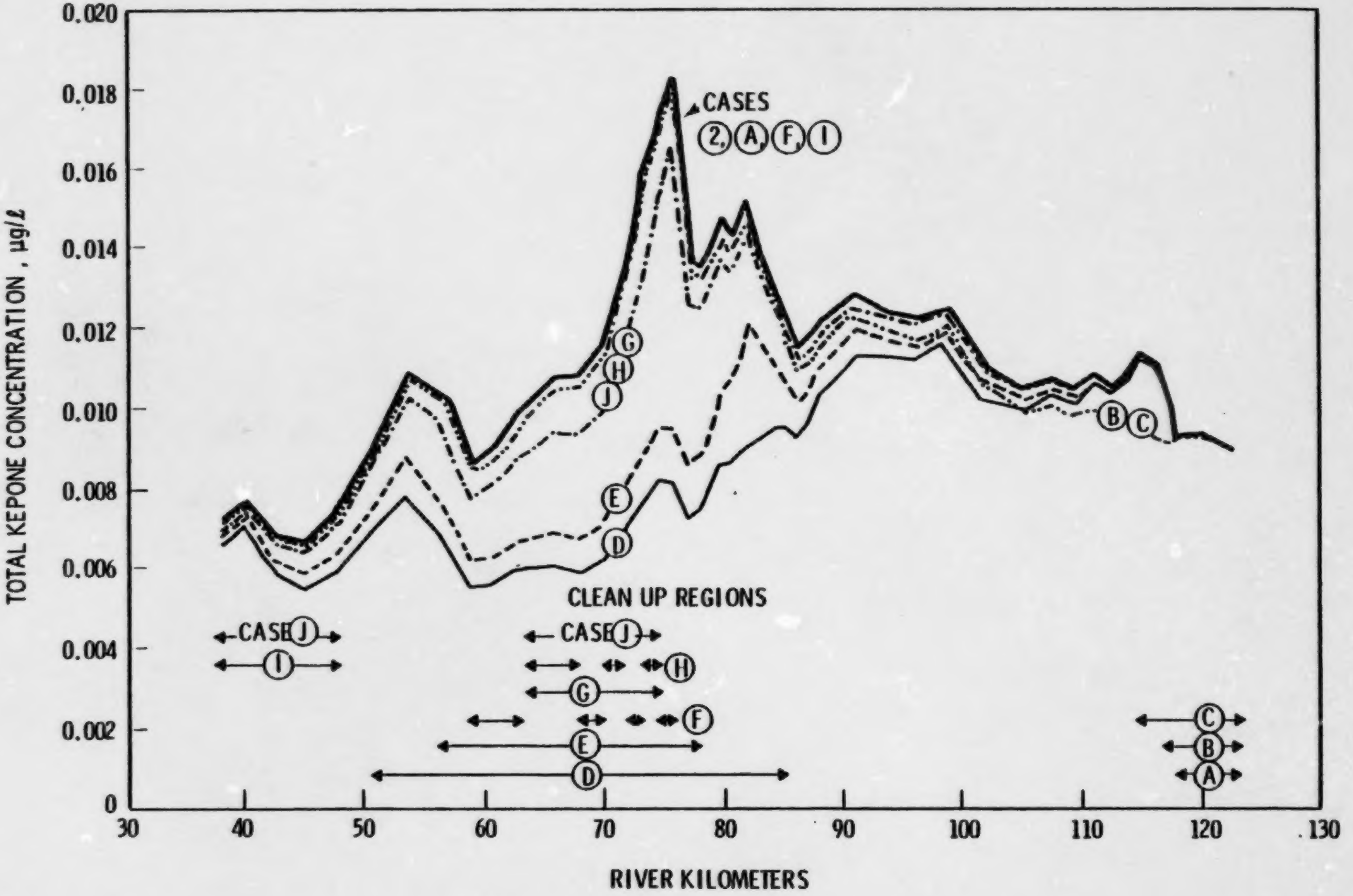


Exhibit VII-17 Changes in Total Kepone Concentrations Due to Partial Kepone Cleanup Activities

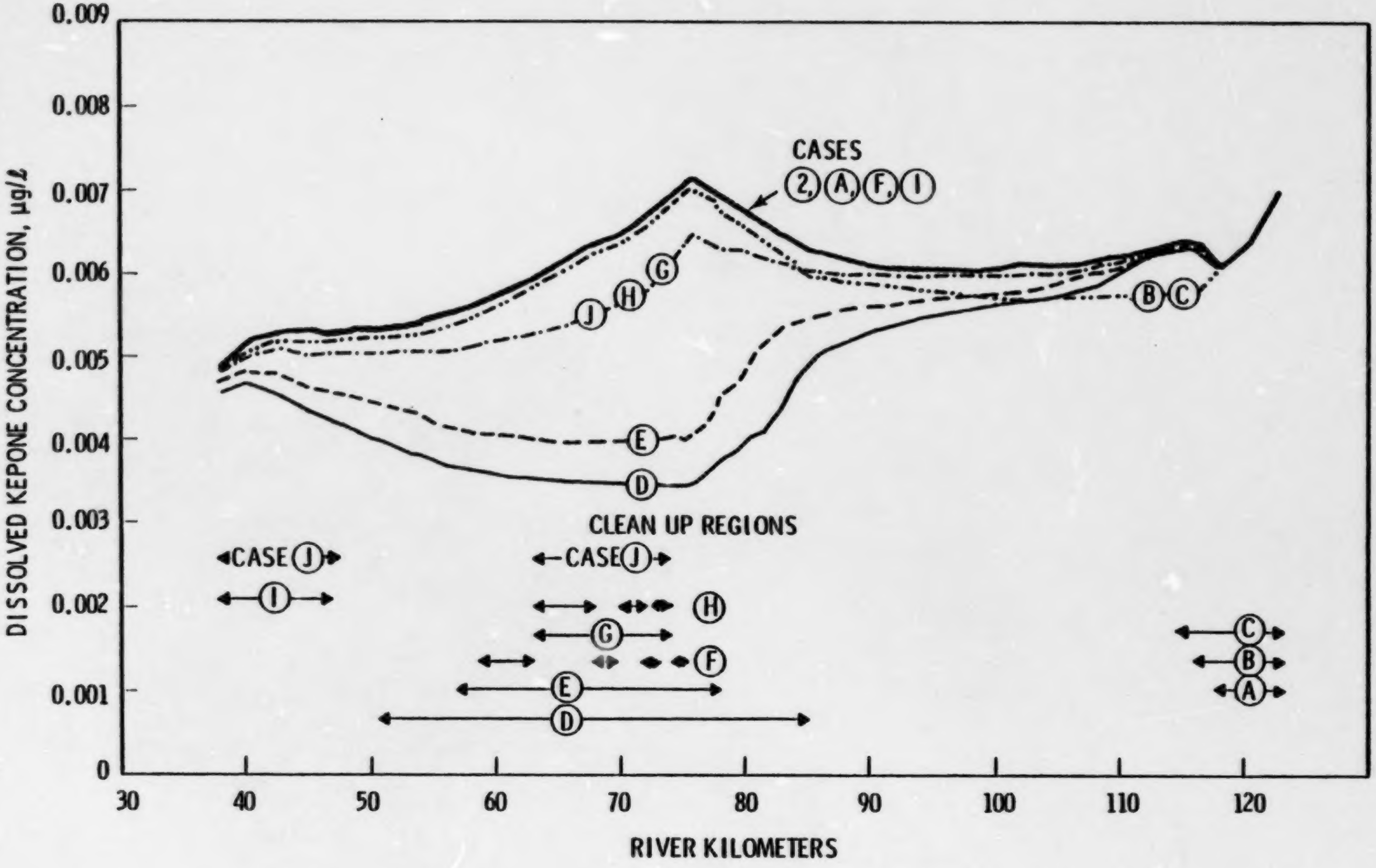


Exhibit VII-18 Changes in Dissolved Kepone Concentrations Due to Partial Kepone Cleanup Activities

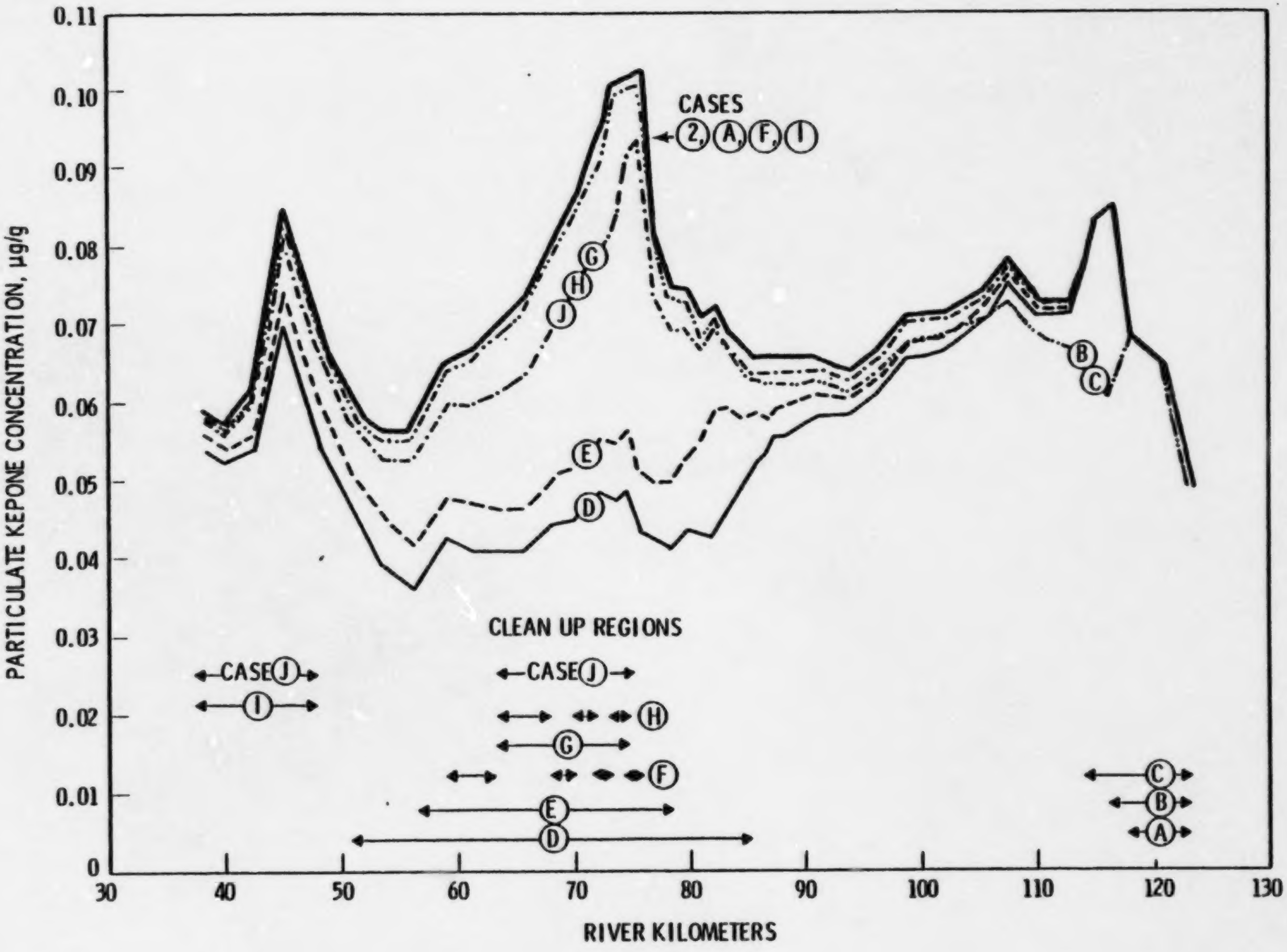


Exhibit VII-19 Changes in Particulate Kepone Concentrations Due to Partial Kepone Cleanup Activities

reach between 56.0 and 78.0 River Kilometer. Cleanup efforts in Cases G and H also demonstrate some reduction (up to approximate 13 percent), however, Case F does not show any improvement. For these five simulation cases there was significant reduction of Kepone levels in water near Burwell Bay.

For the case of lower river cleanup activity (Case I), there is no measurable reduction in the Kepone concentration. Consequently, computer results of Case J (combination of Cases G and I) are the same as those of Case G.

Among these ten cases, Cases D and E reveal significant localized reduction on both dissolved and particulate Kepone concentrations. Although Case D (up to 55 percent reduction of Kepone concentration) is slightly better than Case E (up to 48 percent reduction), comparison of cleanup area sizes for these two cases (34.5 and 22.0 km reaches for Cases D and E, respectively) leads to the conclusion that Case E is more efficient to reduce the Kepone concentration in the river per unit area of cleanup activities.

SUMMARY OF IMPLICATIONS OF KEPONE'S CONTINUED PRESENCE

Hopewell

Certain land areas around the City of Hopewell have contamination from Kepone remaining since closure of Kepone production operations in 1975. These sectors are Nitrogen Park, the Life Science Products site, Station Street neighborhood, Pebbled Ammonium Nitrate plant site, Hopewell sewer system, Hopewell landfill, and the Kepone/sludge lagoon.

Ambient air monitoring in the Hopewell area has shown Kepone to be at a nondetectable level. However, the Kepone on surface soils may be available to the population from windblown particulates and by direct contact.

It is estimated that from 2 to 30 grams of Kepone per day will continue to migrate into the James River in runoff from the general Hopewell area. This incremental increase of residuals to the river system has an insignificant environmental impact relative to the amount of Kepone currently in the river.

James River

The James River represents a much more diffuse source of Kepone than the terrestrial area of Hopewell. There is general Kepone contamination along much of the length from Hopewell to Newport News, with elevated levels in certain sectors. In particular, these are at Bailey Bay and the middle reach of the tidal James known as the "turbidity maximum". The turbidity maximum, or null zone, is the area where saltwater wedge interfaces with freshwater. In the James River it generally occurs from 10 to 50 km above Burwell Bay, depending upon runoff conditions.

Since James River benthic and aquatic species can bioconcentrate Kepone many thousands of times above the ambient water levels, fish, shellfish, and other organisms will be affected by Kepone even with residual concentrations at very low levels. These organisms will accumulate and bioconcentrate Kepone as long as it is available from sediments, suspended sediments, water, or food, As a consequence, the no-action alternative implies that James River fishery products will have excessive Kepone levels for years. Bald eagles, osprey, and other James River birds of prey will continue to be exposed to Kepone from the contaminated fish they eat.

Human contact with Kepone in the James River will probably remain minimal as long as closure orders by the State of Virginia are in effect and obeyed.

Chesapeake Bay

Evidence to date indicates that the no-action alternative under normal conditions would not threaten the viability of the Chesapeake Bay fishing industry. This is supported by historical trends, current sampling data, and transport projections indicating low levels of Kepone contamination entering the Bay.

As early as 1967, oysters taken from the James River contained Kepone residuals. Also in that year, sediment samples were contaminated above detectable levels more than 30 miles downriver from Hopewell (Appendix C, No. 16).

Battelle's simulation results indicate that under average flow conditions despite the large amount of Kepone residing in the James River - only 170 grams/day are transported past Burwell Bay of which 80 percent is in the dissolved state and 20 percent is attached to mobile sediments. This amount would be expected to reach the Bay.

Sediment samples collected from twelve stations in the lower Chesapeake Bay in September 1977 contained no detectable levels of

Kepone above 0.01 ug/g (ppm) (Appendix C, No. 16). Analysis of fish tissues reveals Kepone in some of the Bay's species, although not exceeding the FDA Action Levels.

Based on these facts the question must be addressed as to why Kepone discharges from 1966 to mid-1975 have not resulted in significant Chesapeake Bay contamination as well.

The tremendous dilution and dispersion capacity of the Chesapeake Bay probably accounts for the minimal impact of the small amount of Kepone entering the Bay. In addition the majority of Kepone residuals released from the Hopewell area have probably remained in the James River system due to two natural forces; first, the propensity of Kepone to adhere to sediment rather than remain dissolved in water; and second, the natural sediment trap effect of the null zone or turbidity maximum in estuarine systems.

The impact of the null zone in retaining Kepone in the James River has been well demonstrated, VIMS (Appendix C). Most Kepone concentrations are located in and above the null zone and they persist with time, both over the short term (eight months of sampling) and over the long term as demonstrated from the distribution at depth with cores. (Appendix C, No. 16). Results from extensive James River sediment sampling by the Virginia State Water Control Board exhibit a similar pattern of distribution (Chigges, 1977), and the transport model projections from Battelle substantiate the conclusion of long-term persistence in the null zone (Appendix A). Although the effectiveness of the null zone decreases under extreme flow conditions, the floods of 1969 and 1972 show no evidence of having contributed significant Kepone contamination to the Chesapeake Bay. Rather than net scour, the flooding associated with hurricane Agnes (one of the largest in recorded history) resulted in an increase in the depth of bottom sediment in the tidal James River (Nichols, 1972). However, the situation of the Chesapeake Bay could change, if the FDA Action Levels were made more stringent or a large east coast storm resuspended and transported the Kepone from the turbidity maximum zone.

Although under normal conditions Kepone contamination does not appear to threaten the Chesapeake Bay, utilizing existing data to project long-term trends is always subject to some degree of error. Therefore, continuous monitoring will be required to ensure that should any unsuspected movement of Kepone occur, it will be detected and mitigation efforts implemented before creating a problem in the Chesapeake Bay. In addition to monitoring, the potential of a large east coast storm transporting Kepone into the Chesapeake Bay should be assessed.

VIII. NONCONVENTIONAL MITIGATION METHODS

Battelle Pacific Northwest Laboratories examined nonconventional removal, neutralization, and isolation techniques for mitigating the Kepone contamination problem (Appendix A). This phase of work focused on evaluating alternatives to dredging, as well as treatment and/or fixation processes complementary to dredging for application to Kepone-contaminated sediments in the James River System. Three types of alternatives were studied by Battelle: (1) those which could be used to fix dredged spoils for disposal; (2) those which could be employed to treat elutriate or spoil slurries; and (3) those which could be applied *in situ* as substitutes to dredging. In addition to the work performed by Battelle for the Kepone Mitigation Feasibility Project, the project team investigated other promising areas and continued working with companies whose development efforts have progressed beyond Battelle's initial evaluations. Accordingly, the material presented in this Chapter is wider in scope than that covered in Appendix A and the assessments differ.

DREDGE SPOIL FIXATION

Dredge spoil fixation techniques are designed to prevent water or air pollution by using stabilizing agents capable of solidifying wastes and immobilizing contaminants. Battelle's candidate materials included asphalt, tar polyolefins, epoxy resins, silicates, and elemental sulfur. The desirability of any one fixation agent is based on the characteristics of the contaminant to be bound, the stresses to which the fixed mass may be exposed (e.g. pressure, thermal changes, etc), the environmental consequences of its application, the state of development, and potential costs. The initial evaluations described here concentrate on the agent's ability to isolate the contaminant and to maintain its physical integrity.

Each fixation agent evaluated was subjected to two types of standardized tests: (1) a short-term elutriate test; and (2) a longer-term leach test. All fixation work was performed on a "standard" sediment prepared from a homogenized Bailey Bay sediment sample. The Kepone concentration in the test samples was measured at 1.17 ug/g (ppm). Only commercially available fixation agents were employed and an effort to include all companies currently marketing fixation processes was made. Many of the agents employed are proprietary in nature and, therefore, their compositions are not described.

Silicate Base Fixation Agents

Data obtained on all samples for both elutriate and leach tests are presented in Exhibit VIII-1. The first samples are from fixation tests performed by Ontario Liquid Waste Disposal Ltd. Their process involved the addition of an acidic agent followed by an amending agent with dosing controlled through observation of pH levels. All samples

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Exhibit VIII-1

Kepone Concentrations in Elutriate and Leachate Solutions (µg/ℓ-ppb)

Fixation Type	Elutriate	Time in Hours								Composite of Leachate
		1	4	24	168	336	672	1344	2016	
Silicate Base										
Ontario Liquid Disposal No. 2		0.07	0.08	0.094	0.166	0.524	0.30		0.26	0.17
Ontario Liquid Disposal No. 3		0.05	0.05	0.111	0.157	0.306	0.26		0.51	0.26
Ontario Liquid Disposal-Pickle Liquor		4.10	4.04	3.55	1.75	3.56	1.39	1.59	1.24	2.90
Manchek Colorado No. 2	3.52	1.04	0.99	1.01	1.81	1.74	2.09		3.9	1.90
Manchek Colorado No. 3	1.27	1.34	2.64	0.90	1.30	1.18	0.78		1.76	1.40
Manchek Colorado No. 4	1.91	1.33	1.88	1.31	1.42	1.04	1.02		3.86	2.20
Manchek Colorado No. 5	1.31	0.39	0.54	1.00	1.18	1.27	1.41		2.59	1.49
Chemfix CT-77-2A	0.12	1.90	3.30	2.27	2.93	3.58	3.58	43.9	3.77	1.95
Chemfix I-4	0.012	1.52	2.44	1.62	1.64	2.10	1.42	1.96	2.42	1.50
TJK, Inc. 101	0.078	0.095	0.068	0.059	0.15		<0.21	0.31	0.77	0.77
TJK, Inc. 102	0.055	0.088	0.083	0.088	0.14		0.11	0.49	2.84	0.45
TJK, Inc. 201	0.069	0.21	0.24	0.21	0.16		0.096	0.14	0.81	0.83
TJK, Inc. 301	0.037	0.35	0.13	0.073	0.065		0.073	0.18	3.30	2.01
TJK, Inc. 302	0.055	0.12	0.18	0.14	0.079		0.096	1.89	0.33	0.46
Tunnel Holdings 4A	1.29	0.35	0.45	54.8	0.41		0.53	1.32	2.24	0.86
Tunnel Holdings 4B	0.24	0.046	0.088	0.068	0.67		0.033	0.11	0.15	0.24
Organic Base										
Por Rok Epoxy Grout	<0.037	0.042	0.075	0.021		<0.055	0.034	0.057	0.021	<0.049
Dowell M179	29.3	0.086	0.044	0.018	0.053	0.096	0.21	0.28	0.083	0.074
Sulfur Base										
Molten Sulfur		0.013	0.012	0.017	0.010	0.05	0.029	0.032	0.15	0.17
Sulfaset	0.14	0.5	0.22	0.095	0.20		0.28	0.31	0.29	0.45
Gypsum Base										
Por Rok	Decomposed	0.52	0.47	0.52	0.91	0.82	0.80	1.01	0.74	0.99
Blank No. 1	0.042	<0.066	<0.066	0.076	0.058	0.050	0.22		1.04	0.10
Blank No. 2		0.117	0.04	0.104	0.081	0.11	2.30		0.14	0.26

showed leachate Kepone concentrations in excess of those for untreated sediment.

The second set of samples was prepared by Manchek-Colorado, Inc. They employ an oxidizing agent, a fixative agent, and an amendment using temperature changes for process control. Leachate from these four samples generally contained ten times the concentration of Kepone than did leachate from the untreated sediment.

Two mixtures of the Chem Technics patented fixative called "Chemfix" were evaluated. These samples, labeled I-4 and CT-77-2A, never had a leachate within an order of magnitude of the blank leachate. It is assumed that Kepone was dissolved and was released from the sediment because of the high pH occurring during the mixing and curing steps of fixation. During the leach tests, the free Kepone readily migrated to the leachate water.

Five samples were obtained from TJK, Inc., the U.S. representative of Takenaka. Each is a variation of a basic silicate-based fixation agent developed by Takenaka of Japan. Three of the formulations displayed higher leachate concentrations than standard sediments much like the other silicate-based fixation agents examined. Two of the formulations produced leachate Kepone levels roughly equivalent or slightly lower than those from standard sediments for specific sampling times, but all cumulative leachate levels exceeded Kepone concentrations for the sediment leachate levels.

However, the operational application of fixation techniques to dredge spoil is considerably advanced in Japan over the United States. Accordingly, the Kepone project team has continued to work closely with Takenaka on improvements of their methods as applied to Kepone.

Representatives from TJK indicate that they are currently improving their fixation agents so that their process is amenable for treatment of Kepone contaminated wastes. One approach involves the addition of an appropriate fixative agent to their silicate base which would isolate the Kepone molecules and offset the high pH influence that the base would have on the solubilization of Kepone. Results of the latest fixation efforts on Bailey Bay sediment samples showed leachate Kepone concentrations of only 0.08 ug/l (ppb), and Takenaka believes that they can reach a level of 0.01 ug/l (ppb) to 0.03 ug/l (ppb). The Takenaka technology offers advantage over most fixation processes in that fixation can be performed in-place. Most processes necessitate removal, treatment and then replacement of the fixed material, thus adding considerably to the costs of the process. In addition, the TJK technology has had widespread operational use in Japan under a range of conditions. Large scale projects have been ongoing for several years in contaminated harbors and rivers in Japan, and involve fixation of contaminated industrial sludge, contaminated dredge spoil, and in situ fixation operations on contaminated bottom sediments. Details of the process and applications are covered in Appendix B.

Two samples of silicate-based agents were obtained from Tunnel Holdings Ltd., Inc., of the United Kingdom. Both displayed leachate Kepone levels in excess of those produced by the sediments alone.

In general, most silicate-based agents rely on high pH conditions to set the stabilized material. Kepone is solubilized under these conditions and if the fixation additive does not isolate the Kepone, it will occur in leachate at equivalent or higher levels than is found with natural sediments.

Organic Base Fixation Agents

Por Rok and Por Rok Epoxy Sealant are both grout materials manufactured by Hallemete Division, Sterling Drug Company. Por Rok is a gypsum base material and, consequently, will not retain structural integrity when immersed in water. It decomposed during the elutriate evaluations. When comparing the leach results with those of the natural sediment, there was generally ten times the Kepone leached from the fixed sediment than from the blank. The Por Rok Epoxy Sealant is a synthetic epoxy material which is mixed with a coarse aggregate material and is used as a grout or surface sealant. It produced Kepone leachate concentrations, an order of magnitude lower than those of standard sediments. This stabilization agent shows promise as a means of reducing Kepone releases from spoils. However, widespread use of this material may be limited by production limitations. Furthermore, breakage of the surface sealant would expose the contaminated material to washing and leaching, if the material is used solely for surface treatment.

Dowell M179 is a soil sealant material. It is primarily comprised of a polyacrylamide polymer which resists water percolation. Its action is dependent upon formation of a film-like coating. The crushing employed in the elutriate test, therefore, compromised the integrity of the agent. In order to maintain uniformity in testing procedures, the batch test was retained. The poor response to the elutriate test reflected the breaking of the surface film and subsequent leaching from exposed surfaces. Short-term leaching on the other hand (1 to 4 hours) yielded Kepone levels similar to those from untreated sediments. After 24 hours of exposure the M179 leacnate had a concentration of 0.018 ug/l (ppb), or approximately 1/10th of the concentration found in the blank. Subsequent leachate samples revealed a similar pattern. Consequently, the Dowell agent appears well suited for its intended use as a surface seal and percolation control agent. However, long-term immersion and physical stress could lead to rupture of the film and release of the contaminants.

Sulfur Base Fixation Agents

Two sulfur based approaches were evaluated. The "sulfur sludge" combination involves the mixing of spoils with molten elemental sulfur. The two are rapidly mixed upon contact and allowed to set. The Sulfaset is a proprietary agent distributed by Randustrial Corp., and appears to include both sulfur and cement in the formulation. As is evident from Exhibit VIII-1, the molten sulfur or "sulfur sludge" approach offered one order of magnitude reduction while the Sulfaset was less effective. However, the practicality of molten sulfur for a large scale application to Kepone contaminants would require further evaluation and the environmental consequences are as yet unknown. The Sulfaset produced leachate intermediate between pure silicate based agents and molten sulfur. The Sulfaset sustained a high pH in leachate which is capable of solubilizing Kepone as was the case with the silicate agents.

Asphalt Base Fixation Agents

A preliminary evaluation of asphalt binders was made, but these could not be easily mixed with wet sediments unless heated. The mixing problems with asphalt binders would constitute excessive costs and equipment requirements for the volumes of sediments involved.

A discussion of costs and merits of these fixation agents is included in the appraisal section of this Chapter.

ELUTRIATE/SLURRY TREATMENT

If dredging of the type discussed in Chapter IX were employed to restore the James River System, there may be a need for the capability to treat elutriate, leachate, and/or the entire dredge spoil slurry to prevent subsequent escape and movement of contamination. The applicability of various elutriate treatment approaches depends on the physical-chemical properties of the Kepone, as well as the nature of the liquid stream and/or dredge spoil slurry to be treated.

Photochemical Degradation

The simplest option classified as physical-chemical destruction is photodegradation with sunlight. No data were found on the effect of electromagnetic radiation on Kepone degradation. A set of sample exposure tests, designed to investigate the photolysis of Kepone in sediments exposed to sunlight, confirmed the persistency of Kepone in soils and sediments, and cast doubt on the efficacy of photochemical degradation using incident sunlight.

Amine Photosensitization

In the presence of ultraviolet light and an aliphatic amine, Kepone levels showed marked reductions. Of the solutions tested, ethylenediamine demonstrated a marked trend toward degradation. A solution of ethylenediamine sprayed on dry sediments containing 0.95 ug/g (ppm) Kepone was allowed to stand in the direct sun in an open beaker. After 10 days, the sediment was found to contain only 0.21 ug/g (ppm) of Kepone. This constitutes 78 percent destruction.

Due to the reliance on photolytic action, this approach is limited to action at or very near the surface of the sediment. It, therefore, may have little use on the large volumes of contaminated spoils associated with any dredging activity. Continual tilling could circumvent some of these difficulties foreseen, but land area requirements would still be massive. On the other hand, if costs permit and action were warranted, the approach may be quite appropriate for use in the Hopewell area where soil has been contaminated by atmospheric deposition of windblown particulates containing Kepone. However, before any application of this technique is attempted, further research would be required to determine the impact or possible toxicity of decomposition by-products.

Chlorine Dioxide

Chlorine dioxide, a known powerful oxidizing agent capable of reacting with many organic compounds, was tested on Kepone. Results showed a nonspecific oxidizing action which was too limited to warrant further study at this time.

Ozonation

Ozone, like chlorine dioxide, is noted for its ability to oxidize materials and ozone itself leaves no noxious residues. Ozone, by itself, provided no reduction in Kepone residues. However, research on combined ozonation and ultra-violet irradiation by Westgate Research Corporation exhibited better than 80 percent Kepone removal from the effluent of Hopewell's primary treatment plant when samples were subjected to exposure periods of one hour.

It is concluded that the Westgate process is effective in reducing Kepone levels in aqueous media and could be an effective means of treatment for elutriate, wastewater, and contaminated natural waters. Ultraviolet irradiation processes are limited in that degradation can occur only at exposed surfaces receiving direct irradiation. However, Westgate's continued research on Kepone in turbid samples provided additional promising results. Sediment slurry samples taken from Moody's Creek, a tributary of Bailey Creek which drains the Pebbled

Ammonium Nitrate (PAN) site, were subjected to UV-ozone treatment. As shown in Exhibit VIII-2, there was a significant loss of Kepone, 63.8 percent, in the sediment during the first 30 minutes of reaction time. It is believed that Kepone is being destroyed in the water phase, and that the partition coefficient permits continuous release of Kepone from the sediment to the water. This could explain the relatively constant values obtained in the supernatant analyses. The sediment, about 20 percent by volume, was held in suspension in the "Ultrox" reactor by the ozone spargings (Westgate, 1978). This ability to handle high solid content slurries also holds promise for the direct treatment of dredged slurries.

Use of this process on Kepone should be limited until the extent of Kepone degradation is determined and the toxicity of the by-products is assessed. It appears that degradation occurs by the removal of chlorines from the Kepone molecule forming monohydrokepone.

From these very preliminary but encouraging results, it is estimated that an optimum large-scale portable treatment system could treat 20 to 50 percent solids slurry for 10 to 20 cents per cubic yard, not including equipment amortization. To further define approximate operating parameters and costs for various slurry concentrations further testing is needed. A concurrent chemical analysis should be performed to determine the degree of Kepone

EXHIBIT VIII-2

Kepone Analyses of Westgate Sediment Samples (Conc. in ug/kg) from Moody's Creek

			Mixed Samples							
	Supernate Only		1st Extraction		2nd Extraction		3rd Extraction		4th Extraction	
Sample	Monohydro-kepone	Kepone	Monohydro-kepone	Kepone	Monohydro-kepone	Kepone	Monohydro-kepone	Kepone	Monohydro-kepone	Kepone
Moody's Creek--Feed	0.12	2.29	3.89	95.69	0.77	31.03	1.54	51.44	1.04	45.69
Effluent--30 min	0.52	1.62	1.95	38.61	1.04	26.51	--	11.00	--	4.07
Effluent--60 min	0.59	1.82	1.27	26.44	0.78	21.34	--	7.54	--	2.60
Effluent--90 min	1.44	1.81	1.24	25.73	0.44	21.01	--	5.68	--	1.78
Effluent--120 min	1.00	1.73	1.20	22.29	0.38	13.35	0.08	2.93	--	0.60

	Summation of Mixed Sample		% Kepone Destroyed
	Monohydrokepone	Kepone	
Moody's Creek--Feed	7.36	226.14	0.0
Effluent--30 min	3.51	81.81	63.8
Effluent--60 min	2.64	59.74	73.6
Effluent--90 min	3.12	56.01	75.2
Effluent--120 min	2.66	40.90	81.9

degradation needed to negate its toxicity. This would be an important factor in defining treatment costs.

Cost projections for large treatment plants, developed by Westgate Research, indicate a capital cost of $125,000 to $140,000 per MGD capacity and operation and maintenance costs, including amortization, of $0.11 to $0.12 per 1,000 gallons treated.

If a small capacity elutriate treatment plant were constructed, unit costs would increase considerably. For a 3 MGD plant, the capital costs are $1,300,000 ($433,000 per MGD treated) and the operating costs are $0.23 per 1,000 gallons, including $0.13 per 1,000 gal amortization, and $0.05 per 1,000 gal maintenance.

Radiation

Oxidation can be achieved through direct bombardment with radiation. Given a sufficient dose, virtually all organic materials can be carbonized. The specific action results from excitation of molecular bonds to a point where the bonds break. As a physical destruction methology, no toxic residues are produced when carbonization is carried to completion.

While effective removal can be obtained, (54.7 and 144 megarads of gamma radiation provided 87 percent and 97 percent removal, respectively), large doses are required, and gas chromatographs revealed the presence of a large peak representing degradation products. The latter appear to be partially dechlorinated Kepone, but positive identification has not yet been made.

As an initial appraisal, it appears that degradation efficiencies are a function of radiation penetration. If the optimal penetration distance can be determined, the degradation efficiency can improve. At the present time, there are insufficient data available to pursue radiation as an immediate treatment process. Further evaluation of penetration distances and dose levels may result in an effective unit operation for Kepone amelioration.

Related work has been performed by the Massachusetts Institute of Technology using electron beam radiation.* While this work largely focused on disinfection of municipal sludges, some analytical work was performed to determine the effects of the electron beam bombardment on toxic constituents. High-pressure liquid chromatography revealed that 3, 4, 2' PCB, monochloro PCB, and Monuron at saturation levels in water are totally destroyed when irradiated at dose levels as low as 10 Kilorads. PCB in a solution with 0.5 percent soap was virtually eliminated by a dose of 400 Kilorads. This suggests that positive results may also be obtained with more highly chlorinated organics such as Kepone. However, no investigations on Kepone degradation with an electron beam source have been conducted to date. Consequently, no appraisal of effectiveness on Kepone can be made at this time.

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*Trump, J.G., "Disinfection of Municipal Sludge by High Energy Elections", NSF-RANN grant AEN 74-13016A01.

Catalytic Reduction

A suggested means of destroying chlorinated hydrocarbons is the use of catalysts to facilitate reduction of the chlorine functional groups to free ionic chloride in solution, thereby leaving behind a bare organic skeleton less toxic and more amenable to biochemical attack. Investigation of an approach used by Envirogenics involving a copper-iron catalyst in a reductive column with sand as the working substrate, provided negative findings. Consequently, the approach was abandoned from further consideration.

Carbon Adsorption

During the decontamination efforts in early 1976, the EPA mobile spill treatment unit was brought to Hopewell to help decontaminate washwaters and liquid wastes. At that time, it was noted that carbon adsorption was effective in removing Kepone from solution. Because of this work, no specific laboratory studies were conducted on activated carbon applications to elutriate waters. However, adsorption isotherms produced during evaluation of sorbents for *in situ* application confirm the efficacy of this approach. Therefore, this option is considered viable if elutriate treatment facilities are constructed.

Several of the engineering options for Bailey Bay developed by the Corps of Engineers propose the use of a treatment facility to remove Kepone from contaminated runoff, if determined necessary. The size of such a facility would depend on the size of the holding reservoir and the desired drawdown time.

Field studies have revealed that the bulk of all Kepone in Bailey Creek is associated with particulate matter. Consequently, sufficient treatment may be achieved by construction of coagulation facilities to remove solids with no subsequent carbon adsorption. If this approach is taken, costs are reduced substantially. Cost comparisons on a 50-MGD standard activated carbon plant show that capital costs and operation and maintenance costs (O&M) for an activated carbon facility are $50.4 million and $262,924 per year, respectively, while costs on a coagulation plant are $10.1 million and $551,650 per year, respectively.

The Calgon Corporation has developed a filtration/adsorption wastewater treatment system which shows promise in treating dredge slurry water containing Kepone. In their conceptual design, the dredged slurry would be pumped from the dredge to an impoundment basin where the solids would settle from the water. This basin should be designed to provide adequate settling to remove suspended materials to a concentration of less than 25 mg/l. From the impoundment basin the water would flow to a gravity slow sand filter. The filter would be constructed in a lined earthen basin and would contain about 5 feet of filter sand over 4 feet of gravel. A plastic pipe underdrain would be provided to collect the filtered water and direct it to the adsorption basin. Uniform distribution over the filter would be achieved by flooding the bed with a minimum of 4 feet of untreated water. A surface loading of 0.5 to 1.0 gallons per minute (gpm) per square foot should be maintained.

From the sand filter the water would flow by gravity to an adsorption basin and be directed upflow through a bed containing 4 feet of gravel under 3 feet of 8x40 mesh Filtrasorb activated carbon. A perforated plastic pipe distribution system will insure uniform application of the filtered water to the adsorption bed. This bed will also be operated in a flooded condition to prevent the possibility of channeling. From the flooded section of the bed, the treated water will overflow to a spill way from which it will be returned to the river. The adsorption bed should operate at a surface loading rate of 1 to 2 gpm per square foot of surface.

As suspended solids accumulate on the slow sand filter, periodically the top several inches of sand will need to be removed and replaced. This procedure will prevent excessive pressure drops which would cause the basin to overflow.

At the 2 gpm per square foot of loading on the activated carbon bed, about 10 minutes of contact time will be provided. Assuming an average weight loading of 1 percent on the carbon and a concentration of Kepone of 100 ppb in the dredged water, a total of about 1 million gallons could be treated by each square foot of carbon bed. This would provide a bed life in excess of three hundred days. This represents only a gross estimate and testing should be initiated to confirm loadings and concentrations to be used for design.

At the conclusion of the dredging, the entire sand and carbon beds could be incapsulated and backfilled to prevent future leachate contamination.

Exhibit VIII-3 provides the design criteria on which the capital cost of $3.06 million was estimated. It is noted that the estimate does not include costs for pumping or piping as required to deliver or dispose of the water. Additionally, no costs were included for the impoundment basin required ahead of the treatment system (Calgon, 1978).

Exhibit VIII-3.

Design Criteria for a 50 MGD Temporary Filtration/Adsorption Wastewater Treatment System for Treatment of Kepone Contaminated Dredging Slurry Water

Flow - 25 to 50 mgd

Sand Filter Loading - 0.5 to 1 gpm/sf
Area of Sand Filter - 40,000 sf
Carbon Bed Loading - 1 to 2 gpm/sf
Area of Carbon Bed - 20,000 sf
Superficial Contact Time - 10 to 20 minutes

CAPITAL ESTIMATE

Site Preparation	- 25,000
Excavation	- 150,000
Liner	- 315,000
Underdrains & Spill Way	- 320,000
Gravel	- 350,000
Sand	- 300,000
Carbon	- 900,000
	2,360,000
Engineering	300,000
Contingency	400,000
Total Capital	$ 3,060,000

IN SITU PROCESSES

In situ processes as a category are the newest of the approaches to removal/mitigation of in-place toxic materials. As such, some are less fully developed than other approaches. Several of the more promising new options were selected for testing in the laboratory. Since biological approaches appear to offer little with respect to the removal of Kepone from the James River system, Battelle's work focused on two types of approaches: use of sorbents and use of polymer films. In addition to these approaches, the Japanese Takenaka fixation process previously described under "DREDGE SPOIL FIXATION" might be used for *in situ* mitigation of contaminants. However, indications are that the top few centimeters at the sediment/water interface may be difficult to fix. Consequently, such an application for Kepone, with the present state of knowledge, is far less desirable than removal of the contaminated sediments and fixation in carefully contained dredge spoil sites.

Sorbents

Natural sorbents (such as activated carbon) and synthetic sorbents (such as the macroreticular resins) have been shown to be effective in concentrating organics similar to Kepone. In application, sorbents act much as natural sediments do in maintaining levels of Kepone much higher than those in adjacent waters. Sorbents capable of lower partition values (concentration in water/concentration in substrate) than those exhibited in natural sediments will reduce the levels of dissolved Kepone in the water if introduced to the system. A three-phase equilibrium is established with the highest concentrations of Kepone on the new material, a lower concentration on the sediment, and the lowest concentration in the water.

Based on initial screening results presented in Exhibit VIII-4, sorbents ES863, XAD-4, XAD-2, and Filtrasorb 300 were selected for further study. The three proprietary products are macroreticular synthetic sorbents produced commercially. The Filtrasorb 300 is a commercial activated carbon. In addition to these, a specialty carbon product formed around iron particles became available in time for subsequent evaluations. Allied Chemical had also performed work on anthracite coal.

Based on Allied Chemical's promising initial results with coal, batch adsorption tests were initiated in the Battelle laboratory on a variety of coals. Results indicated that coals tested had less affinity for Kepone than Bailey Bay sediments. Consequently, these could not offer any mitigation promise to the Bailey Bay sediments. However, Bailey Bay sediments are high in organic content and testing on more representative James River sediments should be done before final determinations are made on the applicability of coal.

Exhibit VIII-4

Effectiveness of Sorbents in Accumulating Kepone from Bailey Bay Sediments

Sorbent	Kepone Concentration in Sediments, μg/g-ppm						
	2 wk	4 wk	8 wk	12 wk	Maximum Removal %	Maximum Theoretical Removal, %	Percent of Maximum Theoretical Removal Achieved, %
XAD-2[a]	0.80	0.53	1.19		65	60	100+
XAD-4[a]	1.18	1.06	0.99		32	67	48
863[b]	0.89	0.72	1.21		54	72	75
FILTRASORB[c]	1.21	1.06	1.00	1.33	32	67	48
Magnetic Carbon	1.56	1.23	1.24	1.04[d]	21	--	--
Blank	1.56	1.56	1.16		--	--	--
Magnetic 863	0.77		0.82		31	25	100+
Blank	0.92		1.18		--	--	--

(a) Product of Rohm and Haas
(b) Product of Diamond Shamrock
(c) Product of Calgon
(d) Analysis of the spent carbon revealed 1.07 μg/g Kepone

Although sorbents applied to sediments *in situ* are capable of reducing the availability of a material to the water column, they do not destroy or remove the contaminant. Removal can be achieved, however, if media are made to be retrievable. Laboratory work at Battelle indicates that this is possible through the inclusion of magnetite or iron particles in the sorbent matrix which will render the media particles susceptible to magnetic fields. However, the practical application is unevaluated. The magnetic sorbents would have to be mixed into the river sediments and then recovered. Strong magnetic fields may be required and dispersion of contaminants avoided.

It was noted previously that activated carbon had been successfully applied to remove Kepone from solution. The same is true for any of the sorbents found to be effective for *in situ* evaluations such as XAD-2 and ES863. Consequently, sorbents, if developed for operational application, should be considered as candidates for both elutriate and *in situ* application. In *in situ* use, activated carbon might be considered for application directly to the river without retrieval. This would be done in the same manner as an application of coal, but activated carbon offers a higher degree of adsorption. However, availability of the resultant contaminated carbon to the biota has not been evaluated.

The engineering feasibility and operational utility of the sorbent methods investigated by Battelle have not been evaluated. Accordingly, cost estimates are speculative. However, for comparison purposes, application costs excluding capital costs have been estimated.

In situ Application of Retrievable Media:

Dose Rate - 1.2 lb resins/ft³ sediment

Number of Applications - 2 (potential removal of 90% in highly contaminated sediments, greater in others)

Resin Loss Rate - 25% of resin

Cost of Resin - $120/ft³

Unit Resin Loss Costs - $0.51/ft³ sediment

Application and Retrieval Cost - $0.10/ft³ sediment

Regeneration Costs - $0.25/ft³ sediment

Disposal of Kepone Residuals - $0.07 /ft³ sediment

Total Unit Cost - $0.90/ft³ sediment

In situ Application of Coal:

Dose Rate - 1.2 lb/ft³ sediment (this will reduce Kepone levels in water up to 80%)

Cost of Coal - $20/ton

Unit Cost of Coal Applied - $0.012/ft³ sediment

Unit Cost of Application - $0.02/ft³ sediment

Total Unit Cost - $0.032/ft³ sediment

In situ Application of Activated Carbon:

Dose Rate - 1 lb/ft³ sediment

Cost of Carbon - $0.50/lb

Unit Cost of Carbon Applied - $0.50/ft^3 sediment

Unit Cost of Application - $0.02/ft^3 sediment

Total Unit Cost - $0.52/ft^3 sediment

Polymer Films

Battelle conducted an evaluation of the utility of polymer films to seal Kepone-contaminated sediments in Bailey Bay. However, such films at best would keep the sediments from continually supplying dissolved Kepone to the water column until natural sedimentation might seal in the Kepone deposits. Furthermore, with the need to perforate the sheeting for gas release, the film's sealing integrity is lost and an upward flux of water through the sediments could continually bring Kepone contamination from beneath the film. Thus, the value of applying a polymer film to local areas such as Bailey Bay is questionable.

BIOLOGICAL TREATMENT

In exploring nonconventional removal approaches, biological treatment options were explored in the literature and in limited laboratory studies. Uptake and bioconcentration were investigated for their potential of extracting Kepone from the environment. A summary of the possible biologic approaches that might be further studied for application to the Kepone contamination is given in Exhibit VIII-5.

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Exhibit VIII-5
Possibilities of Biological Amelioration of Kepone

Organism	In Situ		Secondary Treatment	
	Water	Sediment	Water	Sediment
Higher plants e.g. (water hyacinth)	(1) Leaf surfaces may accumulate Kepone However, this is not a practical alternative (2) Not known to metabolize Kepone	(1) Roots not known to accumulate similar compounds. Not feasible (Roots normally free floating) (2) Not known to metabolize Kepone	(1) Surface area/volume required is prohibitive	(1) Not feasible
Fungi	(1) Because of low Kepone concentration in water the use of possible aerobic fungi which degrade Kepone is not feasible	(1) The sediments of Bailey Bay which are highly anaerobic and reducing will not permit the growth of the majority of fungi which are aerobic (2) Anaerobes are not likely to be of any value	(1) Aerobic Fungi would require large shallow ponds for degradation. May be necessary to achieve 100% degradation (2) Accumulation of Kepone by fungi used as biologic filters is possible	(1) Not feasible
Bacteria	(1) Because of low Kepone concentration effective degradation or accumulation may not be possible while the organisms can effectively accumulate Kepone many times. quantitatively the amounts removed would be small compared to current environmental levels.	(1) Anaerobes show best potential for dechlorination of Kepone in Bailey Bay sediments but no species have been identified	(1) Bacteria used as biologic filters is possible (2) Aerobes necessary to achieve 100% degradation	(1) Anaerobic digesters show potential for optimization of degradation
Algae	(1) Low Kepone concentration reduces effectiveness of bioaccumulation while the organisms can effectively accumulate Kepone many times. Quantitatively the amounts removed would be small compared to current environmental levels.	(1) Not feasible (though algae can accumulate carbohydrates anaerobically)	(1) Have shown excellent bioaccumulation of similar compounds	(1) Not feasible
All of the above	Because of the many interactions possible, it is not possible to predict how all four would relate in order to achieve maximal amelioration. The following generalizations can be made: (1) Anaerobes and aerobes must interact so that optimum degradation will be achieved. (2) Normal organism antagonisms may decrease the possibilities of amelioration.			

Kepone attached to plant roots might be isolated, harvested and destroyed by incineration with the plant or organism. However, Battelle's studies conducted on barley showed no uptake of Kepone by this plant. Other rooted plants might concentrate Kepone in a form which subsequently could be harvested and the Kepone destroyed. Since most Kepone resides in deeper river sediments where many rooted plants will not grow, this method is of limited value.

Algal bioconcentration has been demonstrated (Appendix C, No. 4). However, algal uptake and harvesting is also not a useful mechanism for removing Kepone, because uptake would be from the water and not from the sediments where the bulk of the Kepone resides.

Studies with other chlorinated hydrocarbons have shown that they are taken up by plants and that uptake increases with water solubility. However, as indicated, studies to date imply that plant uptake and bioconcentration are not effective mechanisms for mitigating Kepone in the environment.

Biodegradation is a potential approach to eliminating Kepone. Due to the persistence of Kepone and its stability as a compound, biodegradation efforts to date have not shown much promise. EPA Gulf Breeze scientists have demonstrated that Kepone does not degrade (Appendix C, No. 12). Fungal species have been shown to be capable of Kepone degradation by Atlantic Research Corporation, but the fungi would not compete well with natural biota. This application, if practical, would be restricted to a controlled environment such as a Kepone treatment facility.

In general, no biological approaches show sufficient promise for in situ amelioration and only fungal systems have shown promise for application to Kepone waste treatment.

APPRAISAL

In general, many non-conventional alternatives were found to be ineffective or inappropriate for use in Bailey Bay and the James River. The more potentially promising candidates are mentioned in Exhibit VIII-6 and the more readily viable options are discussed below.

Molten sulfur may be a good alternative for stabilizing dredged spoils. However, it is recognized that there could be severe environmental impacts associated with this dredged spoil fixation

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EXHIBIT VIII-6

More Promising Nonconventional Treatment Alternatives Investigated

Approach	Alternative	Results	Costs	Comments
Spoil Fixation	Silicate Bases	High pH solubilizes Kepone	Estimated $\$10$--$15/\mathrm{yd}^3$	Promising to date; the Japanese firm, Takenaka feels their process can be further refined for Kepone and are still making modifications. Only operational large scale in-place fixation technology presently available.
	Organic Bases	Yields 10-fold reduction in Kepone levels	$\$12.53/\mathrm{ft}^3$ fixed	Por Rok Epoxy sealant may be production limited; results slightly more consistent; requires greater than or equal to 50% solids
		Resist leaching; poor response to elutriate test	Not determined	Dowell M 179 - Effective for percolation control.
	Sulfur Bases	Yields 10-fold reduction in Kepone leachate levels	$\$1.30/\mathrm{ft}^3$ fixed	Molten sulfur-effective but serious environmental impacts could result. Sulfur is readily available, has good effectiveness and requires greater than or equal to 50% solids.
Elutriate Treatment	Biological Degradation	Promising strains of fungi and mold	Not determined	Not sufficiently developed

EXHIBIT VIII-6, CONTINUED

Approach	Alternative	Results	Costs	Comments
	Amine photo-sensitization	Degradation occurs at exposed surfaces	$.805/lb for ethylenediamine plus $500/acre application costs yield treatment at $4,000/acre in treating top 1 inch of soil	Inappropriate on dredge spoils, but potential for use on surface soils.
	UV and Ozone	Good decomposition	$433,000/MGD treated on small plant-(capital cost) ($.23/1,000 Gal treated-(O & M costs/yr) (For 50 MGD plant, capital costs are $7.9 million and O & M costs are 2.2 million/yr)	Ultrox (Westgate)-effective for solutions. Doesn't include clarification if needed.
			$.10-.20/yd^3 (preliminary)	Based on 20-50% solids slurries and does not include equipment amortization.
	Gamma radiation	Dechlorinates, by-products unidentified	Not determined	Requires further testing.
	Electron Beam Radiation	Can infer from PCB work only	Not Determined	Requires direct testing.
	Adsorption	Carbon and synthetic resins	$50.4 million-capital $262,924 O & M/yr Based on a 50 MGD plant	Effective, does not destroy Kepone just concentrates and holds it.
		Temporary filtration/ carbon adsorption system	$3.06x10^6 for 50 MGD system (capital cost)	Calgon system does not include costs for piping or pumping as required to deliver or dispose of waters, or the cost of the settling impoundment. Final disposal would include incapsulation and backfilling over the entire sand and carbon beds to prevent future leachate contamination.

EXHIBIT VIII-6 CONTINUED

Approach	Alternative	Results	Costs	Comments
	Coagulation	Removes particulate Kepone	$10.1 million-capital;$551,650 O&M/yr; Based on a 50 MGD plant	Effective for bulk reduction Does not destroy Kepone
In Situ Processes	Retrievable Sorbents	Specific sorbents capable of removal	$.90/ft^3	Effective but requires incineration and regeneration production of media not currently commercially available
	Coal	Initial data suggests no advantages	$.032/ft^3	requires further study
	Polymer Films	Holding action only needed perforation may render ineffective	$.044/ft^3	Effectiveness questioned due to venting requirements. Applicable only to embayments.
	Activated Carbon	Intermediate between coal and retrievable sorbents	$.52/ft^3	Effective--will retard availability but not remove Kepone.
				In all in situ processes, environmental impacts require serious consideration

process because elemental sulfur, while stable in water, readily changes to soluble and potentially toxic forms when mixed with reducing as well as oxidizing sediments. Molecular compounds of concern include carbon disulfide, hydrogen sulfide and sulfur dioxide, and these should be handled carefully. Accordingly, the molten sulfur technique will require additional investigation and evaluation.

Epoxy grout fixation looked promising, but extremely high costs of $12.50 per cubic foot and limited availability eliminated this option from consideration.

The Japanese fixation process is a proven large scale operational in-place fixation technology. This fixation process generally costs $10 to $15 a cubic yard, and eliminates removal costs. However, any in-place fixation technique would have major impacts on the benthic communities.

Based on the study investigations, the UV-ozone process and the temporary filtration/carbon adsorption scheme are deemed best suited for elutriate treatment. Coagulation processes will remove only Kepone associated with particulate matter. Both coagulation and activated carbon must be associated with regeneration processes and Kepone destruction or isolation processes since these processes accumulate the Kepone but do not destroy it like UV-ozone treatment.

However, before UV-ozone treatment is utilized, further investigations are needed to determine the extent of Kepone degradation occurring and the relative toxicity of the degradation by-products.

From the studies on turbid samples, the UV-ozone treatment process may provide a means of removing Kepone contamination from sediment, if the sediments are put in slurries of 20 percent to 50 percent solids. These slurry concentrations are the amounts attainable when the Oozer pump is used for dredging. This is discussed further in Chapter IX.

No major environmental impacts are anticipated with the application of the UV-ozone treatment process other than those associated with construction of the facilities and the increased demand for power. However, as indicated, by-products and/or deleterious residues have not been studied.

Of the in situ approaches considered, all show some degree of effectiveness. The potential of using coal is still not resolved. Based on laboratory comparisons, activated carbon is more appropriate than coal as an in situ additive. Any in situ use of activated carbon or coal, if it proves to be operationally effective, would be limited in application to areas contaminated at less than 1 ug/g (ppm). In areas where Kepone concentrations were greater than or equal to 1 ug/g (ppm), retrievable media or fixation techniques should be given further consideration. The latter exception is made to reflect the fact that at high Kepone concentrations in sediments, the potential reduction in Kepone availability with coal or activated carbon would still allow unacceptable levels of Kepone in the water. For these areas, retrievable media and fixation, if effective, would be costly.

Environmental impacts associated with in situ treatment are not well understood, but in situ treatment will pose many physical, biological and chemical impacts and implications.

There are several aspects of in situ treatment which need further analyses. The most important of these is the effect that the hydrodynamics of the James River and its features will have on the stability, integrity, and behavior of emplaced materials. These aspects will affect the method and location of treatment application.

IX. CONVENTIONAL MITIGATION METHODS

SCOPE and APPROACH

Under its support agreement for the project, the Norfolk District Corps of Engineers: (1) evaluated all potential dredging technology on the world market as well as methods to control resuspensions and concomitant secondary pollution; (2) investigated conventional means for checking Kepone inflows from the Hopewell area into the James River; and (3) made preliminary estimates for removing Kepone from the lower James River via dredging including examination of potential dredge spoil sites. Plans for checking Kepone flows from the Hopewell area involved development and evaluation of 18 engineering alternatives for capturing, stabilizing or removing Kepone in Bailey Bay, Bailey Creek and Gravelly Run. In coordination with the U.S. Fish and Wildlife Service, a qualitative assessment was also made of the environmental impacts which would be associated with a construction or dredging project in the Hopewell area. This chapter summarizes the findings of the Corps of Engineers in accomplishment of the above tasks together with findings of the joint EPA/COE on-site survey of Japanese technology. More detailed information can be found in Appendix B.

POTENTIAL DREDGING TECHNOLOGY

Dredges in use today can be generally divided into three categories: mechanical, hydraulic, and pneumatic. Mechanical dredges normally lift the dredged material above the waterline by means of buckets or scoops of various designs and deposit it in a barge or similar conveyance for transport and disposal. Hydraulic dredges generally move bottom material via a centrifugal pump and pipeline directly toward a disposal area. Pneumatic dredges transport removed bottom material by compressed air. Mechanical dredges can remove bottom material at near inplace density. Hydraulic and pneumatic dredges need dilution water to form the dredged material slurry. Pneumatic dredges need considerably less water than hydraulic dredges.

In the United States today there are basically two categories of dredges: the scoop or bucket action type and the hydraulic suction type. Often considerable turbidity is created at the dredge site during operation of these types of dredges. Bucket action or scoop dredges used in the U.S. include the dragline, the dipper, the grab bucket or clamshell, and the endless chain dredge. The hydraulic suction dredge can be fitted with various mechanisms at the suction pipe inlet which facilitate sediment removal. These mechanisms include rotary cutters or cutterheads, auger-type cutterheads, or high-pressure water jets. Mud shields or dustpans are used on some hydraulic dredges in conjunction with the water jets to reduce secondary suspension at the suction inlet. However, these dredges collect only 10 to 30 percent solids, cause considerable sediment agitation when mechanical cutterheads are used, and induce secondary pollution at the receiving site due to high water content in the dredged material. Consequently, without the use of sediment control measures such as silt curtains, turbidity barriers or "diapers", conventional dredges may pose a serious threat for aggravating an existing, but possibly dormant, in-place pollution problem. Some types of hydraulic dredges in the U.S. include the cutterhead, the plain suction, the dustpan, the hopper, the sidecaster, and the Mud Cat. The Mud Cat dredge is comparable to the cutterhead, except that in lieu of a rotating cutter there is an auger-type horizontal cutterhead. This dislodges the material, and the auger moves it toward the suction pipe. A mud shield surrounds the auger and thereby minimizes mixing of the disturbed bottom sediments with the surrounding water.

Dredging technology in some foreign countries surpasses that of the U.S. This is the case in Japan, where serious problems with in-place toxic substances prompted the development of dredges which are designed to remove contaminants rather than to simply excavate river channels. A significant advancement in dredging technology for removing contaminants was the improvement of a pneumatic dredge. The pneumatic or "Pneuma" dredge, originally developed in Italy, uses hydrostatic head pressure and compressed air to remove contaminated sediments. By applying a vacuum to a pneumatic dredge, the Japanese were able to utilize the dredge in shallow water, thereby eliminating the constraint of needing high hydrostatic head pressure. This dredge is called the Oozer dredge.

Specific advantages for using pneumatic dredge systems especially for contaminant removal include:

1. Continuous and uniform flow;
2. Practically no wear, since there are no mechanisms in contact with the abrasive mixture except for the self-acting spherical rubber valves;
3. Removes up to 60 to 80 percent solids by volume, thus reducing costs and hazards in contaminated dredge spoil disposal;
4. Particularly suited for dredging polluted material, since it causes little disturbance while dredging and, therefore, limits secondary pollution; and
5. Can be readily dismantled for transport over highways.

The following are examples of the pneumatic-type dredges: Pneuma (Italy), Pressair Sand-Pump (Germany), and the Oozer (Japan).

A pneumatic pump is not effective in areas involving considerable debris. Since there is no mechanical cutterhead, large debris would tend to clog the intake. However, depending on the type of debris and sediments, the mechanical cutterhead can also have equal or more serious difficulties.

In addition to the Oozer dredge previously described, the Japanese have also advanced other aspects of dredging technology through the development of a "Clean Up" hydraulic dredge, an antiturbidity system for hopper dredges and the watertight grab bucket.

IHC Holland has designed a series of small dredging units which operate under wet or marshy site conditions. They include three dredging techniques--clamshell grab dredging, backhoe dredging, and cutter suction dredging.

SITE EVALUATION OF JAPANESE TECHNOLOGY

In the review of foreign technology, it was evident that the Japanese were the most advanced in handling in-place toxic substances. A seven-member team consisting of three EPA members and four COE members visited Japan in March, 1978 with the specific purpose of evaluating what potential the Japanese technology offered for mitigating the Kepone problem in the James River. Based on preliminary findings, it was decided to give particular emphasis to the spoil fixation techniques developed by Takenaka Komuten Co., Ltd. and the Oozer dredges developed by Toyo Construction Co., Ltd.

The Takenaka fixation techniques encompass three utilitarian approaches: (1) spoil removal, fixation and then redistribution on land; (2) in situ fixation of surface or near-surface spoil deposits or layers down to 3.5 meters; and (3) fixation of spoil or sediment layers at depths of about 40 meters.

Increased spoil site life, improved secondary uses of inactive spoil sites, foundation stabilization, and fixation of in-place pollutants is possible with these processes. To date, the fixation processes have been used effectively on sludge contaminated by mercury, copper, zinc, cadmium, lead, chromium, and PCB's. Laboratory tests have shown the processes to be effective on arsenic as well. Recent reported tests showed Kepone leachate of only 0.08 ug/l (ppb) from treated Bailey Bay sediment samples, which originally showed Kepone leachate values of0.57. Takenaka believes they can reach a level of 0.01 ug/l (ppb) to 0.03 ug/l (ppb).

Visual inspection of large and small Oozer dredges, owned by Toyo Construction Company, and operating at Yokkaichi Port and the Shibaura Canal, showed no evidence of secondary pollution. At the Shibaura Canal, the small Oozer was dredging oily bottom sediments with no visible secondary pollution. However, passing boats generated considerable turbidity and resuspension of sediments. Operation of the large Oozer "Taian Maru" was observed at Yokkaichi Port. The monitoring closed circuit TV camera mounted on the head of the large Oozer dredge showed little sediment resuspension, and minimal effect on pelagic marine life.

At Yokkaichi Port, the investigating team was also able to observe the "Clean Up No. 3" dredge operated by the Toa Harbor Works Co., Ltd. Comparisons between the Oozer and "Clean Up" dredges were facilitated by the use of both types of dredges at Yokkaichi Port. Both dredges were selected based on their capabilities for dredging high concentrations of solids while causing minimal turbidity. The Clean Up dredge was not operating at the time of the survey and a crew member was working on the cutterhead. Discussions indicated that the "Clean Up No. 3" has had considerable operational difficulties and that modifications to eliminate the operational difficulties significantly reduced the functional capability of the dredge. Earlier comparisons of the Oozer and the Clean Up dredge appeared in the report on Tokyo Takahama Canal Sludge Dredging Project, 1975. This report notes that the turbidities immediately above the suction inlets of the "Oozer No. 1" dredge and the "Clean Up No. 5" dredge were compared with the following results:

Turbidities Immediately Above the Suction Inlets

Dredge	Avg. (ppm)	Max. (ppm)	Min. (ppm)
Oozer No. 1	10.55	16.0	8.0
Clean Up No. 5	16.34	17.7	15.4

It is recognized that even the above comparisons do not reflect rigorously controlled conditions and it would be advantageous to simultaneously and thoroughly test the Japanese Oozer's operating, production and secondary pollution abatement efficiencies against all other dredges. Unfortunately, a survey of the literature and discussions indicate that conclusive complete one-to-one comparisons have not been made. Furthermore, it is highly doubtful that a large scale comparison under sufficient ranges of conditions will be accomplished in the forseeable future. Certainly a direct operational comparison of world-wide dredging in the James River is less than probable. Accordingly, it is incumbent on the Kepone project to make recommendations on the most promising dredging scheme applicable to the Kepone contamination problem in the James River.

On the basis of the available data, observations and discussions, it was concluded that the Oozer pump dredge would be the most practical for the Kepone contaminated sediment conditions existing in the James River. At a minimum, testing of the small Oozer dredge in the James River would provide operating parameters for evaluating potential competing systems. Additionally, the Toyo Oozer has been used effectively with Takenaka's fixation techniques. By pumping slurries with high solids content, the Oozer provides a promising operational combination with the fixation processes.

DREDGE-TYPE APPROACHES FOR BAILEY CREEK, GRAVELLY RUN, AND BAILEY BAY

The following section addresses only the engineering aspects of dredging these locations. The issue of the desirability of dredging and other mitigation approaches is discussed in the section describing the appraisal of the Bailey Bay, Bailey Creek and Gravelly Run alternatives.

The substantially-sized trees in the flood plain of Bailey Creek would require removal of trees, stumps and major roots with a dragline. Under these conditions, a short-based dragline is practical for excavation of the material in Bailey Creek. Due to the inaccuracies of the dragline operation, the minimum depth of excavation would have to be about three feet. The Japanese watertight grab bucket would be ineffective, since debris would be caught in the jaws, rendering its design ineffective. The IHC amphidredge equipped with a grab bucket might be a less environmentally damaging option in Bailey Creek, since it could crawl along the wetlands, thereby reducing clearing and grubbing requirements. Gravelly Run would present more removal complications than Bailey Creek, because numerous bridges and other crossways are within the area to be excavated upstream to the five-foot m.s.l. crossing.

The shallowness and quiescent nature of Bailey Bay suggests use of the Mud Cat dredge in conjunction with silt curtains as practical for dredging there. However, if the Oozer dredge can be transported to the U.S. and placed in operation on a shallow water barge, it is advantageous to use the Oozer for dredging the Bay, since the Oozer minimizes resuspension and removes high percentages of solids. The high solids content of the spoil would reduce elutriate treatment costs and requirements and, also, reduce the potential for secondary pollution from the disposal site.

ELUTRIATE AND RUNOFF TREATMENT AND DREDGE SPOIL STABILIZATION

In considering dredging activity for removing of Kepone-contaminated material, it was important to address the method of conveyance, the type of disposal area, the treatment of the elutriate, and the stabilization of the dredged material. Also, these components were considered as an integrated system and not as separate components. With the presence of continuing Kepone inflows from the Hopewell area, a determination concerning what treatment, if any, was necessary for the waterborne Kepone being carried to the James River.

Elutriate Treatment

Elutriate treatment and spoil stabilization should be applied if Kepone return to the system from disposal areas causes the ambient Kepone levels in the sediment and water of the James River to rise above the 0.015 ug/g (ppm) and the 0.008 ug/l (ppb) levels recommended by the Gulf Breeze Laboratory. Full engineering studies would be necessary to determine, conclusively, whether the safe levels would be exceeded as a result of dredging mitigation activity. For the purpose of comparison, cost estimates were based on an "assumed" need for mitigation, fixation and elutriate treatment and a theoretical slurry composition.

As discussed in Chapter VIII, both the UV-ozone treatment system, proposed by Westgate Research Corporation, and the temporary filtration/carbon adsorption wastewater treatment system proposed by Calgon Corporation are recommended for further evaluation for elutriate treatment. The UV-ozone option seems to destroy Kepone, but the degradation products and their relative toxicity still need to be determined. The use of the temporary filtration/carbon adsorption option may still pose disposal problems if future leachate contamination is to be prevented. At this time, costs for UV-ozone treatment average $433,000 per mgd for small plant capital costs and about $.23/1,000 gallons for operations and maintenance costs.

On a comparative basis for a 50 mgd plant, it would cost over five times more to treat elutriate with conventional activated carbon systems than with UV-ozone, but less than half of what UV-ozone costs with the temporary filtration/carbon adsorption system. Estimates on the temporary filtration/carbon adsorption system exclude pumping and piping costs as required to deliver or dispose of the water from the carbon unit, any impoundment measures needed, and any leachate contamination preventive measures.

Further, preliminary findings indicate that a large-scale UV-ozone portable treatment system would treat 20 to 50 percent solids slurry for 10 to 20 cents per cubic yard, not including equipment amortization (Westgate, 1978). Hence, the additional costs for using the UV—ozone system may not be significant if the settling impoundment needed for the temporary filtration/adsorbtion scheme incorporates significant additional costs or if high spoil fixation costs can be eliminated by treating Kepone contaminated dredge spoil in the slurry form.

Incineration of dredged spoil was discounted because the lack of combustible material in the spoil would make fuel costs alone prohibitive.

Dredge Spoil Stabilization

Based on Battelle's studies, two of the dredge spoil stabilization processes discussed in Chapter VIII offer potential to date, molten sulfur and epoxy grout. Molten sulfur stabilization yielded tenfold reductions in Kepone leaching, but the methodology has not been proven, and environmental impacts could be severe in light of the sulfur by-products. Fixation costs for molten sulfur are estimated at

$1.30 per cubic foot. However, the Japanese process developed by Takenaka does not pose the cost and environmental problems that using molten sulfur would. Recent results, discussed in Chapter VIII, are extremely encouraging concerning the Takenaka fixation process. Efforts to "fix" Kepone are currently underway to further refine their process for this application. Typical fixation cost estimates are $10 to $15 per cubic yard. However, these costs may be larger when the fixation agent for Kepone is further refined.

Por Rok Epoxy Sealant provided similar results to the molten sulfur, but at a cost of $12.53 per cubic foot for fixation. High costs and limited availability made this option unattractive.

Since elutriate and stabilization costs are high, the Oozer dredge has added advantages. It would significantly reduce the volume of elutriate and water content in the spoils, and thus reduce treatment costs. The Oozer is capable of attaining 60 to 80 percent solids in its slurry or spoil. Assuming a low value for the Oozer dredge of 50 percent solids concentration and another 0.5 factor for interstitial water in the spoils, the theoretical volume of water to be removed and treated from the dredged spoils is 1.5 times the volume of spoil dredged. For the purposes of preliminary cost determinations, molten sulfur was used for estimating stabilization or fixation costs and UV-ozone was used to estimate elutriate treatment costs. Use of molten sulfur and UV-ozone processes for determining treatment costs does not indicate a preference for either treatment scheme at this point.

ALTERNATIVES FOR BAILEY CREEK, GRAVELLY RUN, AND BAILEY BAY

The Corps of Engineers evaluated alternatives for checking Kepone input to the James River from Bailey Bay, Bailey Creek and Gravelly Run. The alternatives were limited to structural solutions such as dredging; various types of levee, dam and wall construction; channel improvement or modification; covering or sealing; and other combinations of structural solutions. The analysis included an investigation and evaluation of the engineering feasibility, implications, and costs for removing the Kepone-contaminated sediments from Bailey Bay and Bailey Creek areas. Based on model simulations and biological implications, implementation of these alternatives may be considered viable only if cleanup of the James River were contemplated. However, two of the alternatives offer potential utility and benefits as dredge spoil sites for currently contemplated maintenance dredging. The Corps alternatives for Bailey Bay, Bailey Creek and Gravelly Run are indicated in Exhibit IX-1. Treatment of elutriate from the spoil disposal sites and fixation costs are included in Exhibit IX-1 primarily for those options which merited further evaluation and which would be associated with treatment.

EXHIBIT IX-1 Proposed Alternatives for Conventional Mitigation Measures to the Kepone Contamination in Bailey Creek, Bailey Bay and Gravelly Run

Alternative Number	Proposed Action	Areas Required (acres)	Costs Excluding Treatment	Elutriate Treatment* Costs	Fixation Costs	Total Costs	Comments/ Recommendations
1	Dam and possible treatment plant at mouth of Gravelly Run; treat flows up to and including the 100 year flood level	72	$1.3 million	†	†	†	not recommended
2	Dam mouth of Gravelly Run exclude spillway and divert flow to Bailey Creek for treatment	59	$1.6 million	†	†	†	not recommended
3	Seal Contaminated flood plain areas of Gravelly Run; elevate stream channel, rip rap creek bed, construct control structure at mouth	30 covered 19.6 cleared	$1.5 million	†	†	†	not recommended
4	Relocate existing channel in Gravelly Run into a concrete channel or closed conduit; cover contaminated flood plain with 3 ft. minimum impervious cover	†	†	†	†	†	Increased costs no benefits over those of alter- 3 -not recommended

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* Excluding capital costs or logistics costs for portable unit.

NA Not Applicable.

† Eliminated from consideration, no further determinations made.

EXHIBIT IX-1, CONTINUED

Alternative Number	Proposed Action	Areas Required (acres)	Costs Excluding Treatment	Elutriate Treatment* Costs	Fixation Costs	Total Costs	Comments/ Recommendations
5	Dredge new channel adjacent to existing channel of Gravelly Run; seal side slopes of new one and cover contaminated flood plain. Place flow control structure at mouth	+	+	+	+	+	increased costs; no benefits over alternative 3 - not recommended
6	Dredge all contaminated material in Gravelly Run and place spoil in disposal site 14 in Bailey Bay	30 20 cleared	$1.0 million	+	+	+	includes costs for developing disposal sites- not recommended
7	Dam and possible treatment plant at mouth of Bailey Creek; treat flows up to and including the 100 year flood level	1,060	$9.2 million	NA	NA	+	not recommended as proposed, since treatment of Hopewell's runoff is not necessary
8	Seal contaminated flood plain of Bailey Creek with 3 ft. minimum layer of native cohesive material; flow structure downstream to prevent seepage	464 covered 410 cleared	$20.8 million	NA	NA	$20.8 million	consider
9	Relocate existing channel in Bailey Creek into concrete conduit; cover and seal contaminated flood plain-3 ft. minimum of impervious cover	+	+	NA	NA	+	increased costs; no benefits over alt. 8; not recommended

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* Excluding capital costs or logistics costs for portable unit.
NA Not Applicable.
+ Eliminated from consideration, no further determinations made.

EXHIBIT IX-1, CONTINUED

Alternative Number	Proposed Action	Areas Required (acres)	Costs Excluding Treatment	Elutriate Treatment* Costs	Fixation Costs	Total Costs	Comments/ Recommendations
10	Dredge new channel in Bailey Creek adjacent to existing channel; seal side slopes of new one and cover contaminated flood plain. Place flow control structure at mouth.	+	+	NA	NA	+	Increased costs; no benefits over those of alt. 3. not recommended
11	Dredge all contaminated material in Bailey Creek and place spoil in disposal site 14 in Bailey Bay	513 435 cleared	$16 million	$ 180,000	$89 million	$ 105.2 million	Includes costs for developing disposal sites; not recommended
12	Reduce flows and treatment needs via impounding and diversion of upstream flows, up to 100 year flow level in Bailey Creek, above old sewage treatment plant; diversion via overland pressure conduit to Chappell Creek or gravity conduit to the James River. This alternative would be combined with another to solve the Kepone problem in polluted stream portion below old treatment plant.	405-gravity 428-pressure	$22.1 million-gravity $34.8 million-pressure	NA	NA	$ 22.1 mill. (gravity) $ 34.8 mill. (pressure)	costs do not reflect downstream treatment needs, gravity preferred over pressure due to costs; not recommended

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* Excluding capital costs or logistics costs for portable unit.
NA Not Applicable
+ Eliminated from consideration, no further determinations made.

EXHIBIT IX-1, CONTINUED

Alternative Number	Proposed Action	Areas Required (acres)	Costs Excluding Treatment	Elutriate Treatment* Costs	Fixation Costs	Total Costs	Comments/ Recommendations
13	Dredge all contaminated material from all of Bailey Bay. The top 15 inches would be dredged. Bailey Creek would be impounded and the spoil placed behind the dam		$6.5 million	†	†	†	Since Bailey Bay site was selected for disposal, dredging all of the bay was not necessary; not recommended
14	Construct a 14,250 ft. levee across Bailey Bay from 1 mile east of City Point to Jordan Point and treat entire discharge from Gravelly Run, Bailey Creek and Bailey Bay	NA	$6.8 million	NA	NA	$6.8 million	Consider-costs may rise if elutriate and fixation deemed necessary for any spoil placed behind levee.
15	Construct dam near mouth of Bailey Creek; dredge all of Bailey Bay; place spoil behind Bailey Creek dam; construct dam at mouth of Gravelly Run and divert discharge to Bailey Creek; treatment facility at mouth of Bailey Creek to treat all effluent from the disposal area.	1,167 behind dam	$26.9 million	†	†	†	If eliminate Gravelly Run segment, alt. 15 give same benefits as alt. 7; therefore alt. 15 not recommended

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* Excluding capital costs or logistics costs for portable unit.
NA Not Applicable.
† Eliminated from consideration, no further determinations made.

EXHIBIT IX-1, CONTINUED

Alternative Number	Proposed Action	Areas Required (acres)	Costs Excluding Treatment	Elutriate Treatment* Costs	Fixation Costs	Total Costs	Comments/ Recommendations
16	Construct levee from 1 mile east of City Point across Bailey Bay to Jordan Point; use confined area for maintenance dredging of James River; treat effluent from disposal area	NA	†	†	†	†	Alt. 14 could provide same function as alt 16; therefore, not recommended
17	Construct levee from Jordan Point to east side of Bailey Creek; use confined area for disposal; dredge remainder of Bailey Bay, Bailey Creek and Gravelly Run; proposed spoil site is number 14. Judged to be the best.	30-Gravelly 513-Bailey Creek 20-cleaned Gravelly 435-cleaned Bailey Creek	$ 28.6 million	$ .19 million	$ 95 million	$123.8 million	Alt. 17 without Gravelly Run same as alt. 11 but mitigates Kepone in Bailey Bay also – Consider
18	Cover all contaminated areas of Bailey Bay, Bailey Creek and Gravelly Run with impervious blanket; allow natural drainage patterns to develop	†	†	†	†	†	no known methods to fill area without diking; erosion problems and sealing difficulties; therefore not recommended

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* Excluding capital costs or logistics costs for portable unit.

NA Not Applicable

† Eliminated from consideration, no further determinations made

In all alternatives for dredging in Bailey Bay, it was assumed that sediments with Kepone concentrations greater than 0.1 ug/g (ppm) would be removed. This was based on the ambient levels in the James River outside the Bailey Bay study area. However, subsequent evidence (Appendix C) indicates that fish and other organisms in the lower James, where sediment concentrations are orders of magnitude lower, accumulate Kepone concentrations above the FDA Action Levels. Hence, actual removal or mitigation efforts may have to be aimed at concentrations less than 0.1 ug/g (ppm), necessitating higher costs than anticipated. As noted in Chapter VI, it is recommended that Kepone concentrations in sediments should be reduced below a limit of 0.015 ug/g (ppm).

Appraisal for Bailey Bay, Bailey Creek and Gravelly Run Alternatives

Time constraints on the project dictated that the development of the 18 alternatives be undertaken simultaneously with sampling studies of Kepone concentrations in the area. Accordingly, the assessment of the alternatives reflects engineering and cost considerations, as well as the later derived data on the importance of the alternative in mitigation of critical Kepone contamination.

After investigating Kepone concentrations in Gravelly Run, Bailey Creek and Bailey Bay, it was determined that the concentrations in Gravelly Run were low, and therefore, Gravelly Run would not be considered for mitigation measures at this time, thereby eliminating alternatives 1 through 6 from further consideration.

Assuming a low flow condition in the James River of 21.2 cubic meters per second measured at Richmond, a Bailey Creek flow of 0.57 cubic meters per second, and a high Kepone concentration of 0.3 ug/l (ppb) discharging from Bailey Creek, the Kepone concentration contributed by runoff from the Hopewell area after dilution in the James River, would only be on the order of 0.003 to 0.004 ug/l (ppb) or 3 to 4 ng/l (ppt). This dilution determination does not account for the dilution water being added to the James River below Richmond by other rivers such as the Appomattox. Based on these assumptions, the resultant soluble concentration, under these low flow conditions, is below the 0.008 ug/l (ppb) "safe" limit recommended by Gulf Breeze. Therefore, runoff from the Hopewell area will not require treatment and alternative 7 was eliminated from further consideration.

Alternative 8 involving sealing Bailey Creek flood plain would cost $20.8 million. Alternatives 9 and 10 have increased costs over alternative 8, but offer no additional benefits. Therefore, alternatives 9 and 10 were eliminated from consideration and alternative 8 was retained for further consideration.

Alternative 11 would require fixation costs. Using, for example, molten sulfur, the fixation cost would be $89 million. Elutriate treatment costs utilizing UV-ozone, as an example, would be $180,000 excluding clarification costs, capital costs or logistic costs for a portable unit. Elutriate cost estimates may be high, since use of a dragline does not generate as much elutriate water as estimated. However, costs will be incurred by the necessity to control turbidity from the dragline operations. Later considerations of alternative 17 showed that it offered more benefits. Thus, alternative 11 was eliminated from further consideration.

Alternative 12 does not propose treatment of contaminated areas, but offers flow-reduction schemes aimed at reducing subsequent treatment requirements and costs downstream. Since alternative 7, as a result of not needing to treat Hopewell runoff, is eliminated from consideration and Kepone sediments can be captured by alternative 8 at a cheaper cost, alternative 12 was also eliminated from further consideration.

A number of confined upland and river disposal sites had been considered for disposal of dredged material from Bailey Bay. After evaluating all sites, the Corps of Engineers determined that selection of the optimum James River disposal site was the most feasible disposal approach. Specifically, a site in Bailey Bay, site 14, (Appendix B) was the most reasonable area since the contaminated material would remain in the same relative environment. Selection of site 14 would reduce the amount of dredging required in Bailey Bay by approximately 500,000 cubic yards and would minimize the required pumping distance. Since the Bailey Bay site was selected for disposal, it was not necessary to dredge the entire Bay. This eliminated alternative 13 from further consideration.

Alternative 14, consisting of a levee across Bailey Bay, could be used for maintenance dredging of the James River. Since it was proposed that no treatment of runoff from the Bailey Creek and Gravelly Run watersheds was necessary, alternative 14 has one of the lowest capital costs of any alternative proposed by the Corps. If the James River were dredged specifically to remove the Kepone-contaminated sediments, then elutriate treatment and spoil fixation would probably be required and would add significant costs to this option. Thus, alternative 14 was retained for further consideration.

By eliminating the need for the alternatives concerning Gravelly Run and utilizing the Bailey Bay disposal area, alternative 15 has the same benefits as had alternative 7 and also was eliminated from further consideration.

Alternative 14 can provide the same function as alternative 16. Therefore, alternative 16 is eliminated from further consideration.

Alternative 17 consists of a levee from Jordan Point to the east side of Bailey Creek. Without addressing Gravelly Run, it would provide the same and more benefits than alternative 11. Fixation costs using molten sulfur would cost about $95 million and elutriate costs using UV-ozone treatment would be $190,000 excluding clarification costs, capital costs or logistic costs if a portable unit was used. Thus, alternative 17 was retained for further consideration.

Alternative 18 presented major engineering problems in that there are no known methods to fill the area with impervious material unless the area is diked to control sedimentation. Furthermore, there would be a severe problem with erosion and seepage along the outer edges of the fill area. Thus, alternative 18 did not receive further consideration.

Based on the above evaluation, alternatives 8, 14, and 17 were the only options recommended for final consideration in Bailey Bay. Since alternative 8 only addresses Bailey Creek, it has low priority. However, alternatives 14 and 17 involve mitigation on Bailey Bay and Bailey Creek. Alternative 8, as indicated, would have a final cost of $20.8 million since there is no treatment associated with it.

Biological study implications indicate that actions taken for mitigation in the James may be relatively ineffective in the short term, if they do not address the entire river. Consequently, the total costs in alternative 17, $123.8 million, are excessive if efforts are limited only to Bailey Bay and Bailey Creek. If action is taken on the entire James River, alternative 17 may be desired over alternative 14 for aesthetic reasons.

Alternative 14, with a final cost of $6.8 million, poses the least costly option of the three recommended for consideration. If elutriate and fixation treatment are required for dredge spoils placed behind the levee, then costs will rise. As previously indicated, unless action is taken to remove Kepone from the James River entirely, localized concerted efforts would be relatively ineffective in the short term. However, the costs for alternative 14 are such that it bears further consideration. When dredging the James River for navigational purposes resumes, especially in the zones of heavy Kepone contamination, such as the turbidity maximum zone, consideration should be given for contaminated spoil placement in an acceptable disposal area designed to minimize Kepone reentry to the system. Using the Bailey Bay alternative 14 as a spoil disposal site should be considered because the added spoil would cover and contain much of the more highly contaminated sediments in Bailey Bay. Use of protective diking could serve to isolate the contaminated sediments and prevent their re-entry to the river. The spoil area could be designed to minimize the flow impacts of the entering Bailey Creek and Gravelly Run. Thus, alternative 14 is desirable, independent of any action proposed for the James River.

JAMES RIVER ALTERNATIVES

The Corps of Engineers has completed preliminary estimates for removing Kepone-contaminated sediments from the James River. Parameters used in the estimates are:

1. Excavation be limited to the James River from Hopewell to the James River Bridge; no dredging was considered in tributaries on the James.
2. Excavation depth be limited to 15 inches.
3. Disposal be limited to adjacent sites.
4. Sand for disposal area construction is assumed to be within an economical pumping distance of each site.
5. It was assumed that the Oozer dredge is available to dredge a depth of 15 inches.*
6. Approximately 25 percent excess material will be removed due to over-dredging.
7. The Oozer pipeline will pump material 5,000 feet.

Exhibits IX-2 and IX-3 show the disposal areas proposed for confinement of Kepone-contaminated spoil. Preference was given to sites contiguous to the shore and care was taken to select locations that would have minimal impact on adjacent drainage patterns. Some filling of interior low areas was anticipated, Design levels were

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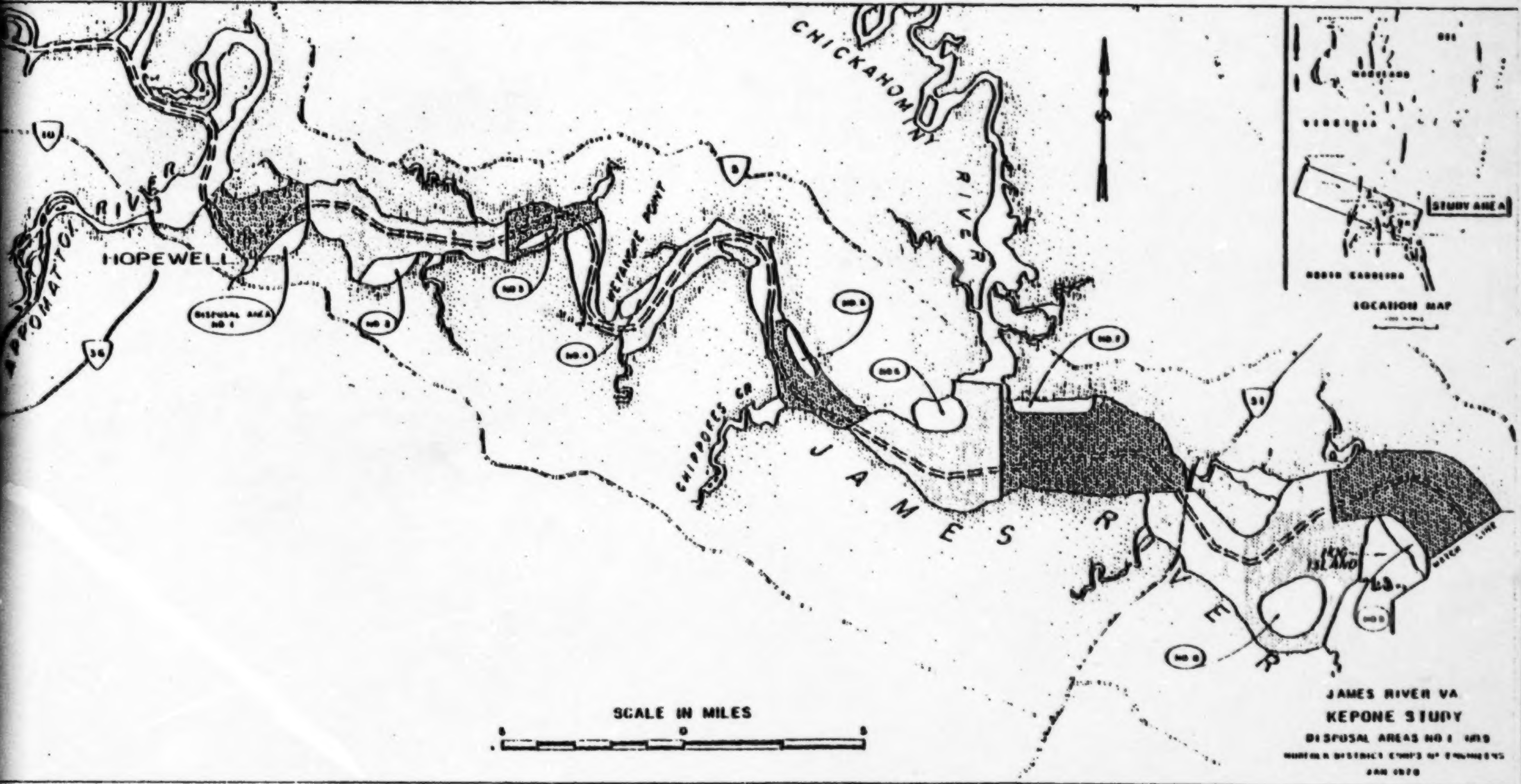
*The Oozer dredge was considered here based on the considerations discussed previously in this Chapter.


HOPEWELL
APPOMATTOX
RIVER
DISPOSAL AREA NO 1
NO 2
NO 3
NO 4
NO 5
NO 6
NO 7
NO 8
NO 9
WEYANOKE POINT
CHICKAHOMINY RIVER
CHIPPOKES CR
JAMES RIVER
HOG ISLAND
STUDY AREA
NORTH CAROLINA
LOCATION MAP
SCALE IN MILES
5
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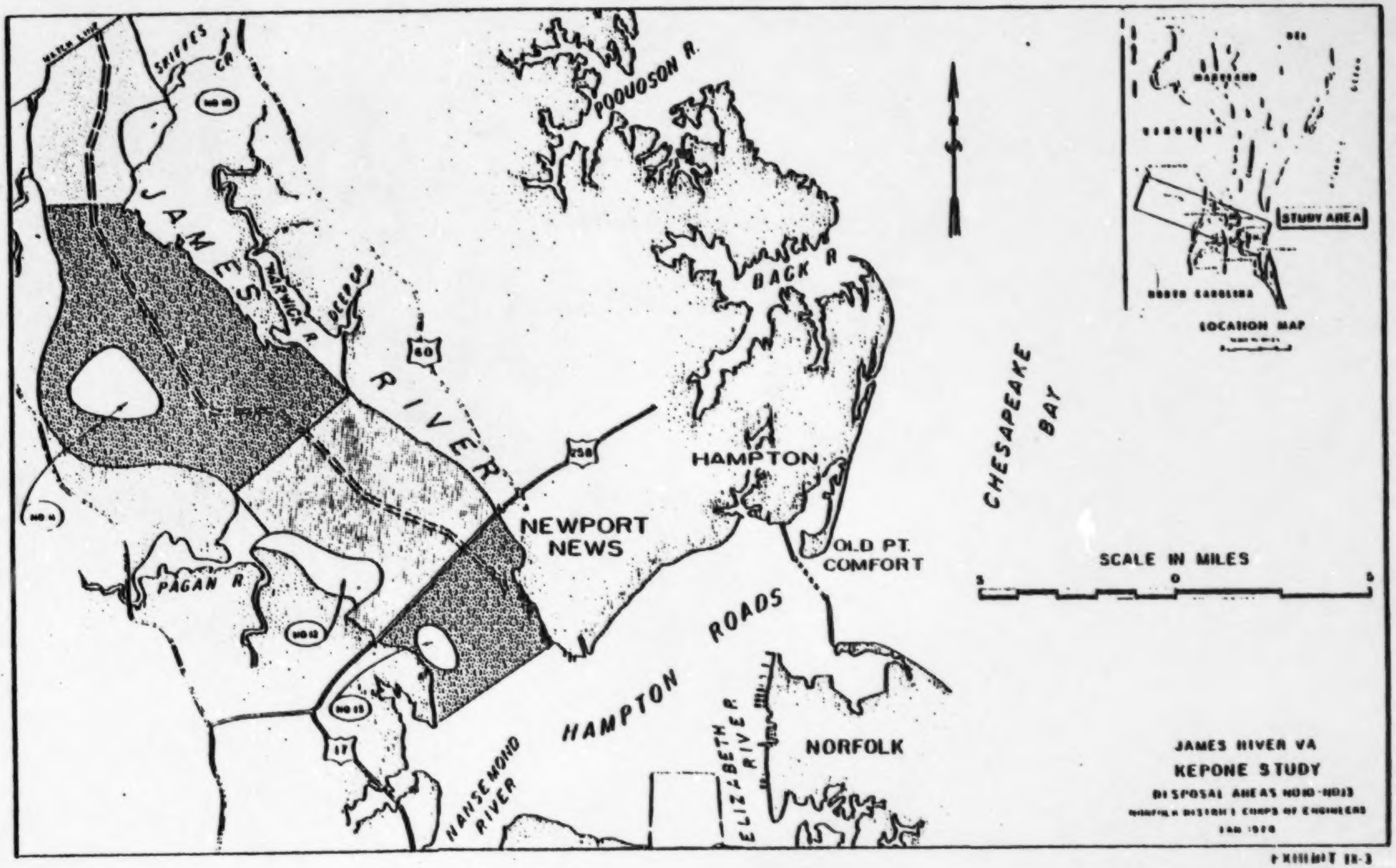
JAMES RIVER VA
KEPONE STUDY
DISPOSAL AREAS NO 1 THRU 9
NORFOLK DISTRICT CORPS OF ENGINEERS
JAN 1978

EXHIBIT II-2


SWIFTS CR
JAMES RIVER
WARWICK R.
DEEP CR
60
258
POQUOSON R.
BACK R
HAMPTON
NEWPORT NEWS
OLD PT. COMFORT
CHESAPEAKE BAY
HAMPTON ROADS
PAGAN R.
NANSEMOND RIVER
ELIZABETH RIVER
NORFOLK
17
NO 10
NO 11
NO 12
NO 13
MARYLAND
VIRGINIA
NORTH CAROLINA
STUDY AREA
LOCATION MAP
SCALE IN MILES
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JAMES RIVER VA
KEPONE STUDY
DISPOSAL AREAS NO10-NO13
NORFOLK DISTRICT CORPS OF ENGINEERS
JAN 1978

EXHIBIT IX-3

based on 100-year flood level and dictated an elevation of 10 feet above sea level datum. Areas not utilized to capacity will be used for future maintenance dredgings. The dredging areas are coded in order to correlate the disposal sites and the dredging area.

Exhibit IX-4 indicates the total costs, dredged quantities, and acreage requirements for mitigating Kepone in the James River. These costs do not reflect any elutriate or stabilization costs which might be necessary to prevent recontamination of the James River. It should be noted that the elevation in Area 1 reflects deposition of material removed from Gravelly Run and Bailey Creek. The selection of Area 1 could supercede the area selected in alternative 14 for Bailey Bay, Bailey Creek and Gravelly Run if total mitigation is proposed for the James River.

It is estimated that it would take one Oozer dredge 120 years to complete the dredging task. Twenty-five Oozer dredges aided by 45 booster pumps could complete the job in about 5 years. With judicious logistics the amount of equipment could be reduced.

Logistics for the equipment needed to dredge the James River is estimated to be $7 million, alone. All estimates provided by the Corps of Engineers contain a 20 percent contingency rate, an engineering and design rate of 12 percent and an administrative cost of 8 percent. Based on dredging alone, cost per cubic yard amounts to

EXHIBIT IX-4

Summary for Conventional Removal of Kepone Contaminated Sediments in the James River

Disposal Areas	Acres	Elevation of Slurry mse	Dredged Quantity in Cubic Yards 15' depth	Dredged Quantity in Cubic Yards 25% Excess Included	Dredging Costs at $4.30/cu yd for 15' depth	Disposal Site Preparation Cost
1	444	10.4	7,440,000	9,300,000	$31,992,000	$3,550,000
2	560	10.3	8,610,000	10,762,500	37,023,000	4,480,000
3	248	7.1	2,790,000	3,487,500	11,997,000	7,610,000
4	411	8.9	6,740,000	8,425,000	28,982,000	11,990,000
5	276	8.4	5,050,000	6,312,500	21,715,000	11,850,000
6	767	6.7	10,440,000	13,050,000	44,892,000	9,200,000
7	736	5.4	12,830,000	16,037,500	55,169,000	15,110,000
8	987	7.4	18,440,000	23,050,000	79,292,000	15,340,000
9	533	9.3	11,300,000	14,125,000	48,590,000	13,950,000
10	872	7.5	14,260,000	17,825,000	61,318,000	11,620,000
11	1572	10.4	37,780,000	47,225,000	162,454,000	17,380,000
12	1635	9.2	28,460,000	35,575,000	122,378,000	20,200,000
13	725	8.4	12,780,000	15,975,000	54,954,000	10,840,000
TOTALS	9766	ROUNDED	176,920,000 (177,000,000)	221,150,000 (221,000,000)	$760,756,000	$153,120,000
				ROUNDED	$761,976,000* (762,000,000)	$220,490,000* (220,500,000)

Total Cost for Dredging and Disposal
Including Contingencies Engineering and Design Studies and Administrative Costs

Total Project Costs	=	Total Dredging Cost	+	Total Disposal Site Cost
$982.5 x 10^6	=	$762 x 10^6	+	$220.5 x 10^6
$1 billion	=	Rounded		

(Total removal and disposal costs amount to $5.55/cubic yard.)

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* Total cost includes contingencies, engineering and design studies and administrative costs.

$4.30. When disposal site costs are included, the total project costs are estimated to be $5.55 per cubic yard. The disposal sites would be Craney Island-type enclosures, sealed in the same manner as the sites considered in the Bailey Bay alternatives. Extrapolating the costs for the preparation of site 14 in Bailey Bay, estimates of site preparation for each disposal area are determined in Exhibit IX-4. The total dredging cost would be about $760 million and the total disposal site cost would be $220,500,000, excluding elutriate treatment or spoil fixation costs.

The results of this preliminary analysis present the magnitude of removing 177 million cubic yards of contaminated material from the James River at a cost of $982,500,000, or close to $1 billion.

Dredging	$762,000,000
Disposal	220,500,000
Total project cost	$982,500,000

If elutriate treatment and spoil fixation costs are considered, the total cost of the project ranges from $1 to 7.2 billion depending on the treatment chosen. Elutriate treatment costs for UV-ozone were figured using a portable UV—ozone unit and a treatment rate of $0.23/1,000 gallons, excluding logistics or capital costs or possible water clarification costs. A summary of a complete treatment cost estimate for treating the James River sediments with intra-basin disposal is presented in Exhibit IX-5.

Battelle, in separate efforts, determined costs and some environmental consequences for other in situ mitigation proposals. These are also included in Exhibit IX-5.

MITIGATION OF ELEVATED CONTAMINATION AREAS

Certain areas of the James River contain more Kepone than others as a result of dispersion and other hydrologic parameters. Bailey Bay and Tar Bay contain significant amounts as a result of their proximity to the discharge source of Hopewell. Due to the characteristics of the turbidity maximum significant amounts of Kepone also lie in the sediments of the turbidity maximum zone.

It was previously indicated that partial cleanup of the James River might have little effect in the short term range in mitigating Kepone impacts. It could, however, reduce the amount of closure time in the long range perspective. Also, it is imperative that a strategy be developed for the protection of Chesapeake Bay. As indicated by the modelling effort, no significant impacts are predicted for the Chesapeake Bay, but the predictions can change as a result of increased data inputs and more sampling data.

EXHIBIT IX-5

Treatment Cost Estimates For Alternatives On The James River

	Without Dredging	With Dredging
Dredging With Oozer Dredge (COE)*		
Molten Sulfur Stabilization	N/R	$ 1.0×10^9
TJK Fixation with Removal	$ 6.2×10^9	$ 7.2×10^9
Elutriate Treatment - UV-ozone	$ $1.8\text{-}2.6 \times 10^9$	$ $2.8\text{-}3.6 \times 10^9$
Elutriate Treatment - temporary scheme filtration/carbon adsorption	$ 12.4×10^6	$ 1.01×10^9
UV-ozone for Sediments	$ 40.3×10^6 $\$26.6\text{-}53.1 \times 10^6$	$ 1.04×10^9 $\$1.03\text{-}1.05 \times 10^9$
In Situ (Battelle)*		
Application of Retrievable Sorbents	$ 6.2×10^9	N/R
Application of Coal	$ 2.2×10^8	N/R
Application of Activated Carbon	$ 3.6×10^9	N/R

N/R - Not required.

*The areas used by the COE for determining dredging alternative costs were slightly different than those used by Battelle in determining non-conventional alternative costs. The relative ranking of alternatives due to cost determinations remains unchanged even with this areal difference.

In an effort to determine where cleanup activities should begin if the Chesapeake Bay were threatened or if some mitigation efforts were undertaken in the James River, the Battelle model was used to answer the following questions about mitigation:

1. What will happen to the Kepone migration pattern and its concentration level if a part of the Kepone in the river bed is removed by physical, chemical or biological methods?

2. Where is the optimal location for Kepone removal to reduce the Kepone level in the River?

Computer simulations were performed on various reaches of the river. It was assumed that for each case, Kepone in the bed at a certain part of the tidal James River was completely removed. This was accomplished by changing boundary conditions to assume no bed Kepone in the restored reach. For all cases, fresh-water input discharges were assumed to be 247 cubic meters per second. Computer results during the maximum ebb tide after 1-month simulation for these cases were then compared with the no clean-up case, in order to assess the effectiveness of the Kepone cleanup activities. The resultant predictions are in terms of percent reductions of Kepone levels in the associated water columns.

Among the cases examined, middle river mitigation efforts are predicted to be the most beneficial. Based on model simulations, cleanup of the 34.5 Km reach between Hog Island (Km 50.5) and Brandon Point (Km 85.0) would remove 55 percent of the Kepone from the associated water column. Cleanup activities in a smaller segment of this reach, the 22 Km segment between Black Point on Jamestown Island (Km 56) and Claremont (Km 78), would reduce Kepone levels in the associated water column by 48 percent alone. The entire 34.5 Km reach is in the zone of the turbidity maximum. The model simulation also indicated that cleanup of Tar Bay and Bailey Bay would reduce ambient Kepone levels in the associated water column by approximately 15 percent within the vicinity of the bays, but cleanup of Bailey Bay and Tar Bay would have little effect on the total amount of Kepone leaving Burwell Bay.

Thus, even though the physical removal of Kepone contaminated sediments in "hot spot" segments of the James River will reduce significantly the Kepone concentrations, the net effect will only be evident in the long term. The dynamics of the river such as tidal fluctuations, bottom scour and salt wedge migration, lessen the immediate impact of hot spot cleanup.

Estimated treatment costs for cleaning up the 34.5 Km reach, the 22 Km reach and Bailey Bay and Tar Bay are presented in Exhibit IX-6. Preliminary estimates are based on dredging volumes determined in

EXHIBIT IX-6

Preliminary Estimates for Mitigation Of Kepone In Areas Of Elevated Concentrations

	Bailey Bay to Tar Bay	Black Point to Claremont	Hog Island to Brandon Point
Numbered Disposal Sites Involved	1,2	6,7,8	5,6,7,8,9
Cubic Yards Dredged	16,050,000	41,710,000	58,060,000
Dredging Cost And Disposal Costs Based On $5.55/yd^3	$ 89.1 million	$ 231.5 million	$ 322.2 million
Fixation*			
Molten Sulfur at $35/yd^3	$ 561.75 million	$ 1.46 billion	$ 2.03 billion
TJK with Removal at $10-15/yd^3	$161-241 million	$ 417-626 million	$ 581-871 million
Elutriate Treatment* UV-Ozone	$ 1.12 million	$ 2.91 million	$ 4.06 million
Temporary Filtration with Carbon Adsorption Assume A 50 MGD Plant Per Spoil Site	$ 6.12 million	$ 9.18 million	$ 15.3 million
UV-Ozone For Sediments* at $0.10-0.20/yd^3	$2.4-4.8 million	$6.3-12.5 million	$8.7-17.4 million
In Situ			
Application of Retrievable Sorbents at $0.90/ft^3	$ 390 million	$ 1.01 billion	$ 1.41 billion
Application of Coal at $0.03/ft^3	$ 130 million	$ 33.8 million	$ 47.0 million
Application of Activated Carbon at $0.52/ft^3	$ 225 million	$ 586 million	$ 815 million

*Without dredging costs added.

Exhibit IX-4. The treatment schemes are only used for estimates and pilot efforts should be done to determine the viability of any scheme before it is used for the purpose of mitigation. Pilot testing would also permit further refinements of these estimates.

Appraisal for James River Alternatives

It is evident that mitigation efforts on the entire James would involve enormous costs both environmental and economic. For example, any *in situ* fixation, dredging or sorbent application would have large scale impacts on the benthic life of the River. Before any final action recommendations are made, comprehensive engineering, environmental, economic and social studies, including field demonstrations, should be undertaken to determine the extent of associated impacts.

From the project findings and observations, the Oozer dredge appears well suited for removing the Kepone contaminated sediments with the least amount of hazard and mechanical difficulties. The most effective means of treating elutriate appear to be the UV-ozone treatment developed by Westgate Research Corporation and the temporary filtration/adsorption system developed by Calgon Corporation. A direct comparison between the two processes is not possible without further field testing since each process has its benefits and disbenefits. Fixation processes which showed the most promise for

Kepone reduction in Battelle's laboratory tests were molten sulfur and epoxy grout. However, cost and availability limitations and potential environmental impact make these options less than desirable. Fixation efforts by the Japanese process are extremely encouraging and require close examination. If the fixation process can be further refined, it would be a more attractive option from an economic and environmental cost standpoint. Further, the Japanese process is the only in-place fixation technology that is currently available on the market today for large scale applications.

Based on laboratory experiments, activated carbon application appears to be a promising in situ mitigation process. However, if future data demonstrate the effectiveness of coal, its application should be considered over activated carbon in all areas except those contaminated at greater than or equal to 1 ug/g (ppm) Kepone, where retrievable media or fixation techniques should be considered. The latter exception reflects the fact that at high sediment Kepone concentrations, coal or activated carbon would still allow unacceptable levels of Kepone in water.

Although a substantial reduction in Kepone concentrations could be achieved by dredging in the turbidity maximum, the model simulations predict that the reduction of Kepone availability would only be evident over the long term, while having little impact on the immediate Kepone problem. A more effective full-scale clean up strategy would involve clean up at the points of inflow, such as Bailey Bay, and proceeding down the river. Bailey Bay would also provide an advantageous location for pilot mitigation efforts from a logistical standpoint.

Due to the significant Kepone contamination of the reach between River Kilometers 50.5 and 85.0, consideration should be given to isolating any dredge spoil removed from this area when navigational dredging is resumed. To facilitate handling, treatment and isolation, consideration should also be given to using the Oozer dredge since it can deliver a slurry of 60 percent to 80 percent solids with little secondary pollution and resuspension.

One further consideration would be the placement of contaminated dredge spoil, taken during navigational dredging from Hog Island to Brandon Point, into a spoil site in Bailey Bay and Tar Bay. This practice would help reduce the Kepone impacts from the contamination in the bays while at the same time remove some Kepone from the heavier contaminated river reaches.

ENVIRONMENTAL ASSESSMENT OF THE CONVENTIONAL ALTERNATIVES FOR BAILEY CREEK, GRAVELLY RUN, AND BAILEY BAY

An environmental assessment was prepared by the Corps with cooperation from the U.S. Fish and Wildlife Service for the 18 alternatives on Bailey Creek, Bailey Bay, and Gravelly Run. An environmental assessment covering the entire James River mitigation effort would be extensive and requires more thorough analysis beyond the scope of this project. Exhibit IX-7 summarizes the environmental impacts associated with the initial alternatives for Bailey Bay, Bailey Creek and Gravelly Run. In view of the disadvantages associated with alternative 18, it was eliminated from consideration in the matrix. Cumulative impacts from construction of any combinations of the alternatives do not appear to be any greater than the summation of the individual impacts generated by component alternatives. However, the sequence of component action may reduce the construction impacts. For example, dredging Bailey Bay last in any plan would presumably remove the contaminated sediments released during implementation of any measures in Bailey Creek and Gravelly Run. Dredging Bailey Bay first would allow recontamination of the "cleaner" Bay substrate with materials suspended by construction activities in the Creek and Run.

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EXHIBIT IX-7

SUMMARY ENVIRONMENTAL IMPACT MATRIX: KEPONE FEASIBILITY STUDY

Alternative no. and description	Type of possible impact										
	Social	Land use	Archeological historical (Data needed)	Wetlands	Estuarine Bottom	Upland wooded and agricultural	Pollutant mobilization	Air quality	Water quality	Ecological systems	Borrow or disposal areas
1 Gravelly Run Dam	None expected	Some disruption at Continental Can during flooding; logging truck access stopped	No known impact	Flooded during high runoff to 13.1(m.s.l.) No tide	Minor impact	Dam site area lost; Also spillway area	Reduced by dam and treatment works	Minor effect during construction	Enhanced by treatment works; sedimentation during construction	Tidal flooding eliminated; Character of area changed; Input to James lost	Little impact due to relatively small amount of material
2 Gravelly Run Dam w/diversion to Bailey Cr	None expected	None expected	None expected	Same as 1	Minor impact	Low value woods lost at dam site and spillway and diversion route	Not reduced but controlled for other treatment	Minor during construction	No change in WQ sedimentation during construction	Same as 1 plus additional runoff to Bailey Cr	Same as 1
3 Cover Gravelly Run bottom and construct spillway	None expected	None expected	Areas covered; excavation still possible	Wetlands destroyed; Possible to rebuild some in run	Minor impact	No loss due to construction or operation	Sediment leaching and movement controlled; Runoff not affected	Suspended particulates from earth moving operation	Reduction of leaching from bottom; Affected by storm-water runoff	Loss of wetlands; Clean upland meadow may develop	Sedimentation; Loss of habitat; Social impact due to truck haul
4 and 5 not considered											
6 Dredge Gravelly Run to disposal area; Treat effluent	None expected	None expected	Some impact at disposal area and treatment plant site	Wetlands destroyed can be rebuilt in place	Bottom area permanently covered by disposal area	Loss due to dredged material haul road	Some possible from dredging; Little from treated disposal effluent	Minor impact from equipment; odor; some hydrocarbon emissions	Turbidity from dredging; Little pollution from disposal area	Removal of some marsh and swamps	Site unspecified
7 Bailey Cr; Dam at mouth and treat runoff	None expected	None expected	Possible impact from dam site	Tidal influence blocked; Character of wetlands changed; Trees may be flooded	Bottom area decreased	Dam site spillway and treatment plant site lost	Decreased to aquatic environment; Unknown to upland environment	Temporary impact fr construction machinery	Improvement over present state; Reduction of inputs to Bailey Bay	Wetlands and marshes degraded; Possible replacements	Minor impact due to small amount of material

EXHIBIT IX-7
(continued)

Alternative no. and description	Type of possible impact										
	Social	Land use	Archeological historical (Data needed)	Wetlands	Estuarine Bottom	Upland wooded and agricultural	Pollutant mobilization	Air quality	Water quality	Ecological systems	Borrow or disposal areas
8 Cover Bailey Cr Bed to 5' m.s.l. and construct spillway	None expected	No conflict with current plans	Possible sites covered can be excavated later; minor impact at construction pts	Wetlands destroyed; Some rehabilitation may be possible	Bottom area decreased	No impact anticipated fr construction or operation	Decreased or stopped fr creek bed; Runoff not affected	Suspended particulates fr earth moving operation	Reduction of leaching and bed load introduction of pollutants to James; Runoff not affected	Possible long-term reduction of pollutants in regional food chain; Loss of wetland habitat	Sedimentation at site; Loss of habitat; social impacts due to truck haul
9 and 10 not considered											
11 Dredge Bailey Cr to disposal area; Treat effluent	Disposal area may have impact; Dredging minor impacts	Conflict may arise in choice of borrow area	Sites lost if present	Wetlands destroyed	Bottom area decreased	Loss due to dredged material haul road	Turbidity with attached pollutants possible during dredging; Little from disposal area	Odor possible; Hydrocarbon emissions from sediments	Turbidity depending on dredge used	Wetlands destroyed; Possible reclamation of low marsh; Pollutant cycling stopped	Truck haul to west side of Bailey Bay
12 Dam Bailey Cr upstream of Rt. 156 bridge; Divert runoff to James River at Bailey Bay	Evacuation of 25 structures	Some of pool area precluded from development	No known sites disturbed	Wetland areas above bridge may be altered by periodic inundation	None lost; Above tidal influence	Loss at dam site	Little effect except to reduce lower creek erosion	Short-term effects during construction	Sedimentation during construction; No change during operation except to hold storm water	Some affect on wetlands otherwise little change	Required for dam construction material; Some short-term effects if commercial area
12A Diversion to Chappell Cr (more info needed on Chappell Cr)	Same as 12 but also along pipeline R.O.W.	Same as 12	Same as above except study of R.O.W. may be needed also	Same as above	Same as above	Same additional loss along Rt. 646 pipeline route	Same as above	Same as above	Same as above	Diverted water may have impact on Chappell Creek watershed	Same as above

EXHIBIT IX-7
(continued)

Alternative no. and description	Type of possible impact										
	Social	Land use	Archeological historical (Data needed)	Wetlands	Estuarine Bottom	Upland wooded and agricultural	Pollutant mobilization	Air quality	Water quality	Ecological systems	Borrow or disposal areas
13 Dredge all of Bailey Bay and pump into a disposal area	Possible visual from disposal area	Minor impact	No known sites disturbed	Little impact	Up to 1 meter of low productivity bottom removed; Cleaner area remains	Little impact	Minimized by dredging method and control measures; Minor impact over present condition	Little impact from dredging operations; Some impact fr levee construction	Impacts from turbidity; Little impact fr spoil area due to treatment	Benthos destroyed; Polluted material removed; Pollutant cycling lessened	Disposal area on west side of bay; Little impact if pollutants stabilized
14 Dike Bailey Creek and treat runoff from the inclosed area	Possible visual impacts	Little impact	Minor impact except along dike construction corridor	Cut off from tidal influence; Major long-term impact	Cut off from tides and fish and benthos migration	Little effect	Leaching and runoff to James River stopped by treatment	Minor impact during construction	Impounded water may become eutrophic	Cycling of pollutants fr diked area will continue; Aquatic system degraded	Disposal of James River channel sediments w/treatment will have little added impact
15 Dam Bailey Cr, dredge bay, and use Cr as a disposal area; Dam Gravelly Run and divert to Bailey Cr; Treat effluent	See Alternatives 2, 7, and 13										
16 Included in alternative 14											
17 Construct levee in Bailey Bay along east shore	See Alternatives 6, 11, and 13										

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